The ENGLISH ELECTRIC JOURNAL

Queen's House from Lincoln's Inn Fields.

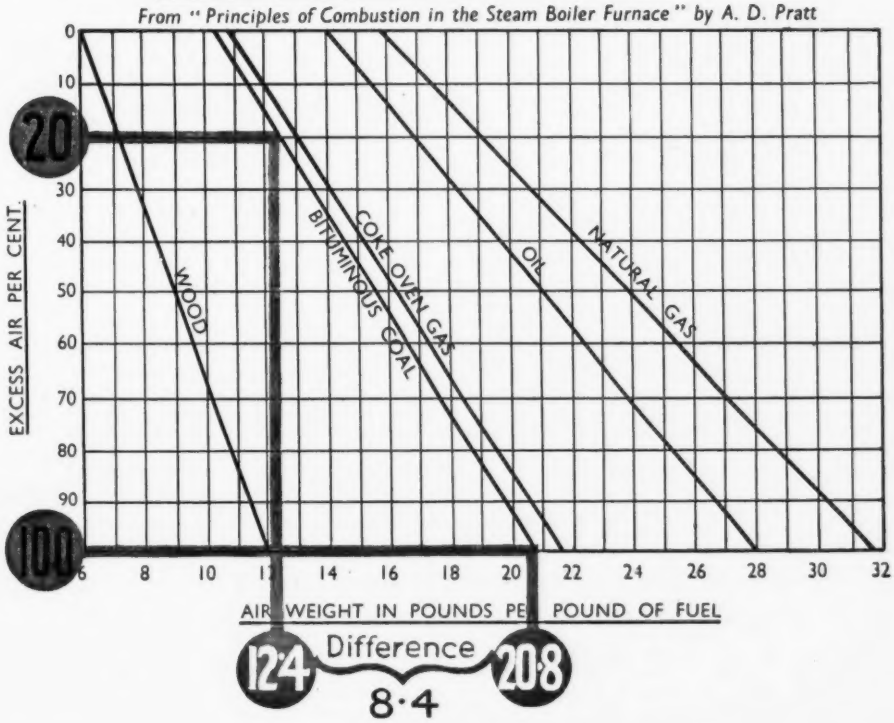
All rights of republication, including translation of articles, are reserved.

Two-high Reversing Hot-Mill for Non-ferrous Material. The whole of the mill controls are concentrated on the Single Operator's Desk shown in the foreground of the illustration.

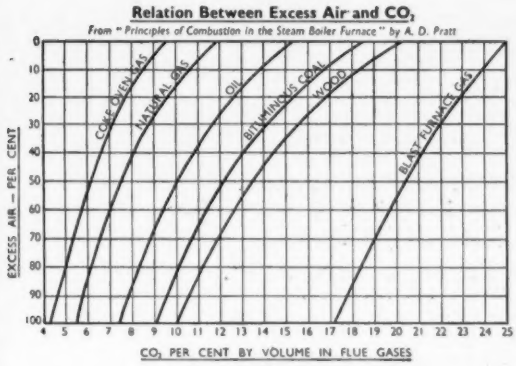
What does CO_2 mean?

Relation Between Excess Air and Air Weight

From "Principles of Combustion in the Steam Boiler Furnace" by A. D. Pratt



(For convenience we reproduce below the chart from the first advertisement of this series.)



OUR first advertisement of this series showed that in effect CO_2 percentage was without meaning as a measure of combustion efficiency unless the analysis of the fuel was known, whereas the percentage of excess air provided a measure which was independent of the type of fuel.

It will be seen from the chart above that with Bituminous Coal each 10% increase in excess air means an increase of approximately 1 lb. of air for combustion per pound of coal, or between 20% excess air (15.4% CO_2) to 100% (9.1% CO_2), there is an increase of 8.4 lb. of air per pound of coal, i.e. 112 cubic feet at 70°F. and atmospheric pressure.

This unnecessary loading of the forced draught fan motor is obviated by the use of Bailey water cooled furnace construction, which permits minimum excess air to be carried over a very wide range of load.

This is the second of a series of three advertisements

BABCOCK & WILCOX LTD. 34 FARRINGDON STREET LONDON, E.C.4

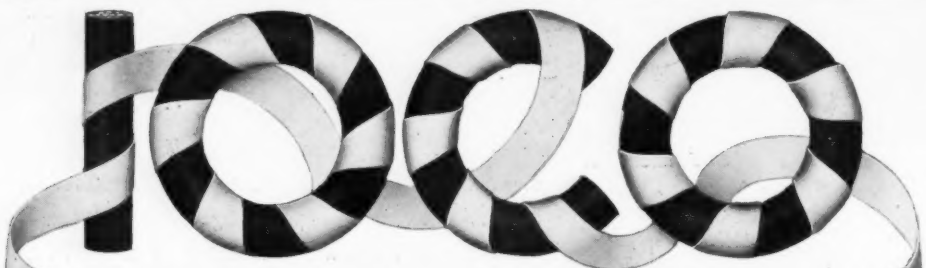
SUPERIORITY

comes from infinite technical care —and experience

TAYLOR TUNNICLIFF PORCELAIN

Taylor Tunnicliff & Co. Ltd., London Office, 85, Streatham Hill, London, S.W.2. Tel.: Tulse Hill 5255-6.

TAS/TT. 2.



INSULATIONS

"LINAPEX" VARNISHED CLOTHS AND TAPES.
Straight Cut, Bias Cut. Seamless and stitched.

"LINAPEX" VARNISHED SILKS AND TAPES.

"LINAPEX" OILED PAPERS.
For Telephone Insulation etc.

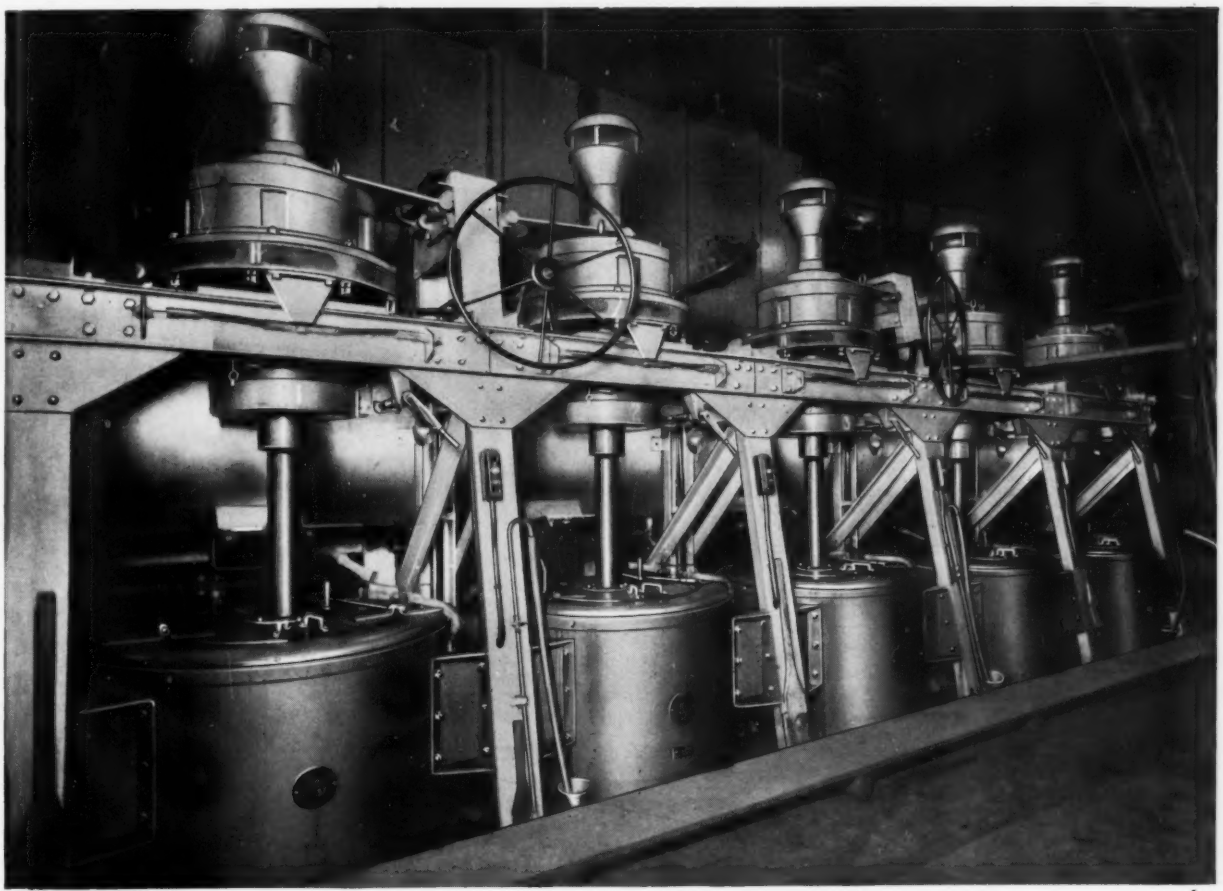
"FORMAPEX" MIOCARTA SHEETS
Grade I, B.S.S 547 - P.F.
Grade II. B.S.S. 316. - P.O.
Punching Quality - P.Q.

"FORMAPEX" MIOCARTA TUBES.
Wrapped P.G. Moulded P.P.

"FORMAPEX" VARNISHED PAPERS
B Quality. Coated for wrapped tubes.
I. Quality. Impregnated for moulded tubes, etc.

Write for Booklets on Insulation—post free.

THE IOCO RUBBER & WATERPROOFING Co. LTD.
GLASGOW.



H. 136

Five 42" × 24" Direct Electrically-driven Centrifugals, 1,450 R.P.M., with Fan Ventilation, Push Button Control, Regenerative Braking, etc.

The above Centrifugals are giving 20 charges per hour curing Sugar.

FOR SEPARATING
FILTERING
DRAINING
CLARIFYING
DEHYDRATING

BROADBENT

ELECTRICALLY-DRIVEN

CENTRIFUGALS

INCORPORATE ALL THE VERY LATEST DEVELOPMENTS IN ENGINEERING & METALLURGICAL PRACTICE TO GIVE BETTER EFFICIENCY

RAPID ACCELERATION
HIGH SPEED
LARGE THROUGHPUT

and for many secret processes

ASK for Technical Catalogue No. 3936

THOMAS BROADBENT & SONS LTD. – HUDDERSFIELD

Telegrams Broadbent, Huddersfield

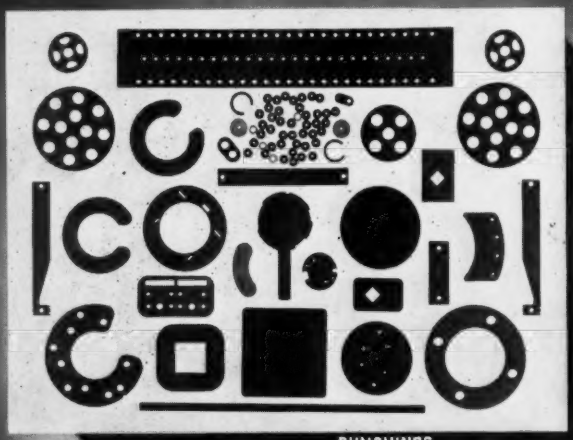
ALSO AT LONDON, LEICESTER, MANCHESTER, NEWCASTLE, GLASGOW

Telephone 1581 (4 Lines) Huddersfield

CENTRIFUGALS OF ALL TYPES IN A WIDE RANGE OF SIZES

PAXOLIN
REGISTERED

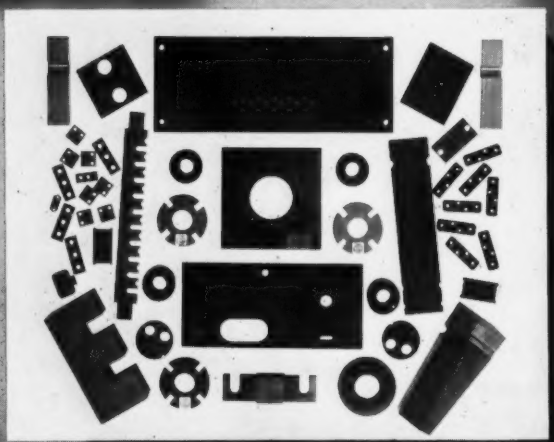
INSULATION
PUNCHINGS AND MACHINED PARTS



PUNCHINGS

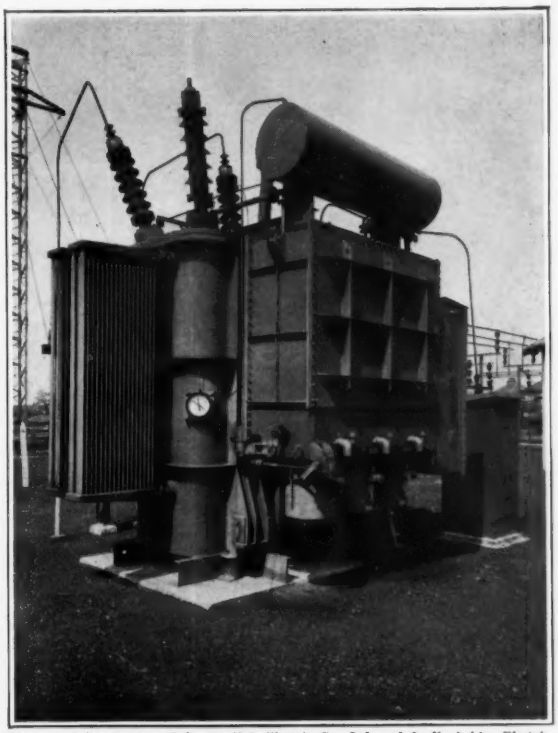
Only half the weight of aluminium, yet tough and easily machined, "Paxolin" lends itself to a multitude of mechanical as well as electrical applications

Write for Pamphlet No.PN-1/38



MACHINED PARTS

THE MICANITE & INSULATORS
COMPANY LIMITED.
WALTHAMSTOW LONDON, E.17



Photograph by courtesy of the English Electric Co. Ltd. and the Yorkshire Electric Power Co.

STERLING INDUSTRIAL PAINTS

Suitable for use on
Transformers
Switchgear
Kiosks, etc.

We should like to draw your attention to the STERLING THREE-COAT PROCESS which is suitable for outside gear of all types.

Please write for descriptive leaflet.

STERLING INSULATING VARNISHES—
Supreme since 1891.

THE STERLING VARNISH COMPANY, LIMITED
Fraser Road, Trafford Park,
Manchester 17.

Telephone: TRAfford Park 2231.
Telegrams: "Dielectric" Manchester.

WALKER'S LION PACKING

"LION"

The 'KING' of PACKINGS
indicates
significant leadership

•

CATALOGUE No. H6 FREE ON REQUEST

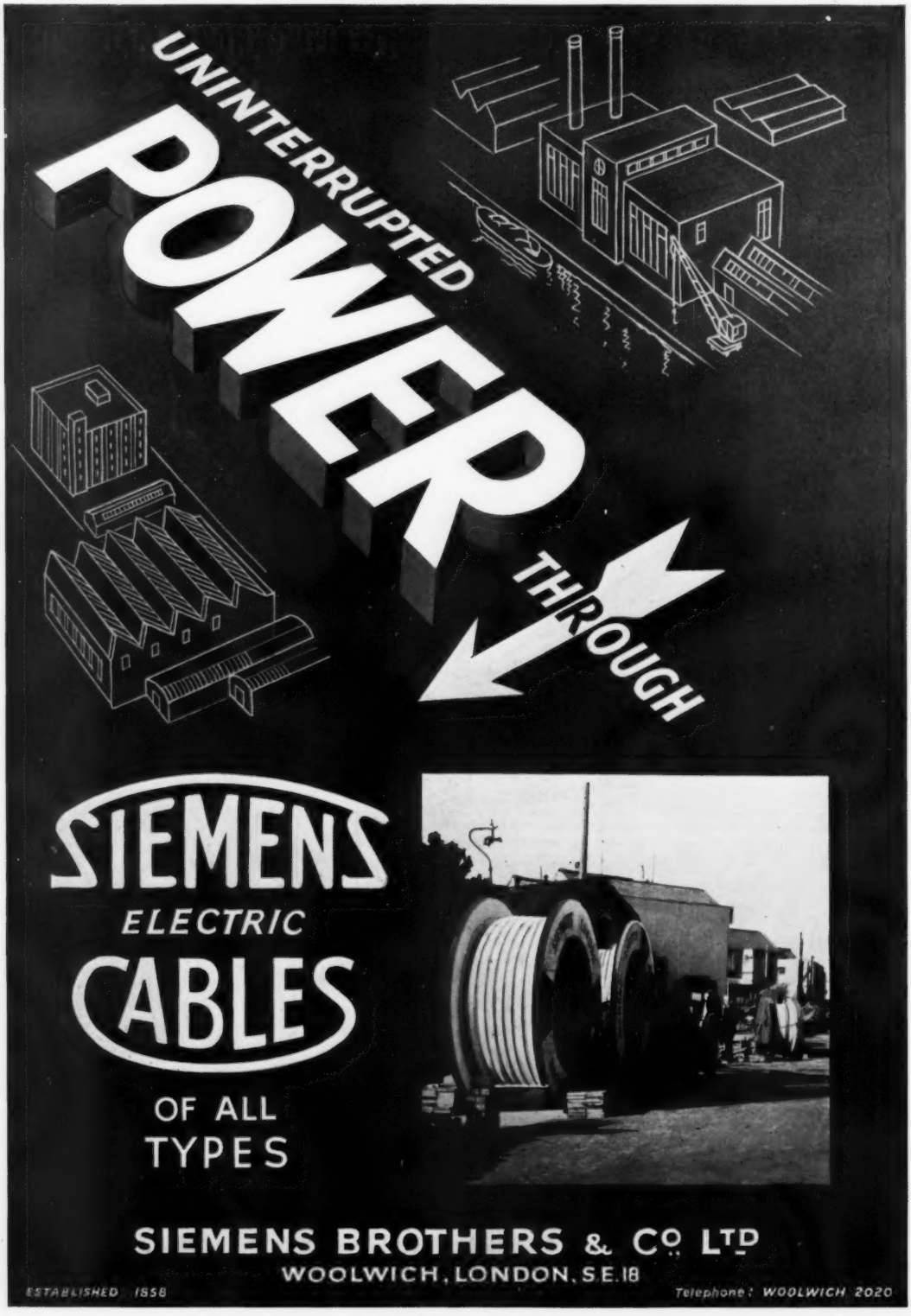
PROGRESS
in
DESIGN
for
Modern Packing and Jointing requirements
is our
responsibility

We are at your service

•

JAMES WALKER & Co. LTD. PACKING & JOINTING SPECIALISTS

Telephone: WOKING 2255 WOKING, SURREY Telegrams "LIONCELLE" WOKING


UNINTERRUPTED
POWER
THROUGH
SIEMENS
ELECTRIC
CABLES
OF ALL
TYPES
SIEMENS BROTHERS & Co. LTD
WOOLWICH, LONDON, S.E.18
ESTABLISHED 1858
Telephone: WOOLWICH 2020

The English Electric Journal

Vol X. No. 3 JUNE, 1941. One Shilling

CONTENTS.

	PAGE
ELECTRIC DRIVES FOR COLD STRIP ROLLING MILLS -	70
THE FUNDAMENTALS OF STEAM TURBINE GOVERNING - -	76
ARC FURNACE TRANSFORMERS -	84

All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

In the first article in this issue Mr. H. S. Carnegie gives a review of modern practice in electric drives for cold strip rolling mills. The Author points out that in recent times there has been a great increase in the speed of rolling of both non-ferrous and steel strip and that this, coupled with the fact that industry now requires very flat and uniform strip, makes the use of drum or reel tension coilers desirable, except when the thicker gauge strips are being rolled. The first section of the article deals with the subject of tension control, which is an important factor in obtaining accurate gauge control, and goes on to discuss the many advantages of the electrically-driven constant-tension reel. This is followed by a brief description, accompanied by photographs, of a number of cold-strip mills of both the reversing and non-reversing types, incorporating electrically-driven reels.

The frontispiece shows a 2-high hot reversing mill for non-ferrous material. This mill is driven by a 4,000 (peak) H.P., D.C., motor, with a maximum speed of 51 R.P.M., which gives a rolling speed of 400 feet per minute. The mill motor is supplied from a 1,200 H.P. Ilgner set. The live roller tables are driven by three 50 H.P. direct current mill-type motors, which are synchronised with the mill, means being provided for reducing the speed of the entry table in accordance with the reduction of thickness required.

It is to be noted that all the mill controls, namely, those for the mill motor, the live roller tables, the screw-down gear, and the lubricating pumps are concentrated on a single operator's desk. Normally the main control lever operates both the mill and the roller tables, but the tables can be independently controlled if so desired.

The second article, entitled "The Fundamentals of Steam Turbine Governing," is by Mr. H. G. Yates, who is in charge of research work in the Company's Steam Turbine Department. The article explains in detail the basic principles underlying the governing of prime movers, and outlines the application of these principles to the design of governing gears for steam turbines.

In the concluding article Mr. C. C. McLaren deals with Transformers for Steel-Melting Arc Furnaces. The heavy demand for high quality steels for the armaments and aircraft industries has brought the arc furnace to the forefront, as this type of furnace is very suitable for the use in bulk of scrap metal, and close control of the metallurgical constitution of the steel can be obtained. Static transformers are the only converting plant required, and the necessary power can be readily taken from any large electric supply system.

The Author discusses the salient features of the modern arc furnace transformer, and the various problems with which designers were faced in its development.

Electric Drives for Cold Strip Rolling Mills.

By H. S. CARNEGIE, M.I.E.E., Chief, Special Engineering Section.

General.

Cold-strip rolling mills may be of the non-reversing or reversing single-stand type, or the stands may be arranged in tandem, widely or closely spaced.

Incidently, as pointed out by C. E. Davies, for a given finishing speed an equal number of stands operating as reversing mills will tend to give a greater output of rolled material than when the same stands are used as a tandem train.

For thicker material, loose coilers at the finishing end may be employed, but for wider and thinner material, driven drum or reel coilers are essential to produce the required flat and uniform strip, while the use of back or drag tension is increasing as its importance in gauge control is better realised.

Single-stand mills may be driven by single-speed motors, such as plain induction motors, but up-to-date practice has shown a decided preference for variable-speed mills, particularly with the Ward Leonard type of control, which give a wide choice of threading, winding speeds and flexible operation, resulting in an increase in the output of strip.

Tandem-mills are almost necessarily driven by D.C. motors, and although small tandem-mills widely spaced may be fed from a constant-voltage system with field control on individual stands, it is preferable in all cases to supply the tandem-mill group of motors from a variable-voltage system, such as a Ward Leonard or rectifier equipment.

The speed of rolling has been greatly increased of late, non-ferrous strip now being rolled from 300 to 600 ft. per minute and even above, while with steel strip, speeds of 1,000 to 1,500 feet per minute are quite normal with large mills. In America the speed of tinplate reduction mills has been raised to over 3,000 ft. per minute.

Tension Control.

The build-up of the strip on the winding reel for a given mill speed necessitates a reduction in the r.p.m. at which the reel is driven. Also for a constant tension it is obvious that the torque required must necessarily increase since the outside diameter of the coil increases, such an increase of diameter often being of the order of 2 : 1 or above. If d be the reel diameter in inches, and W the weight of the coil of strip in lbs. per inch width, then the outside diameter D of the coil in inches is :

$$D = \sqrt{k.W + d^2} \quad \text{or} \quad W = \frac{D^2 - d^2}{k}$$

where k is 4.6 for steel
12.8 ,, aluminium
4.0 ,, copper

Due to this decrease in speed and increase in torque of a reel motor during a pass at a given strip speed, the horse-power required for the reel drive at constant tension will remain constant ; a like effect also applies to an unwinding reel as it builds-down during a rolling pass ; e.g., for a tension of 8,000 lbs./in^2 on a strip 18 in. $\times$ .06 in. at 500 ft./min. the reel H.P.

$$= \frac{8{,}000 \times 1.08 \times 500}{33{,}000} = 131 \text{ H.P.}$$

Where a reel is driven from a mill through a friction slipping clutch with a brake on the unwinding reel, approximately constant torque is exerted for a given adjustment of the clutch and

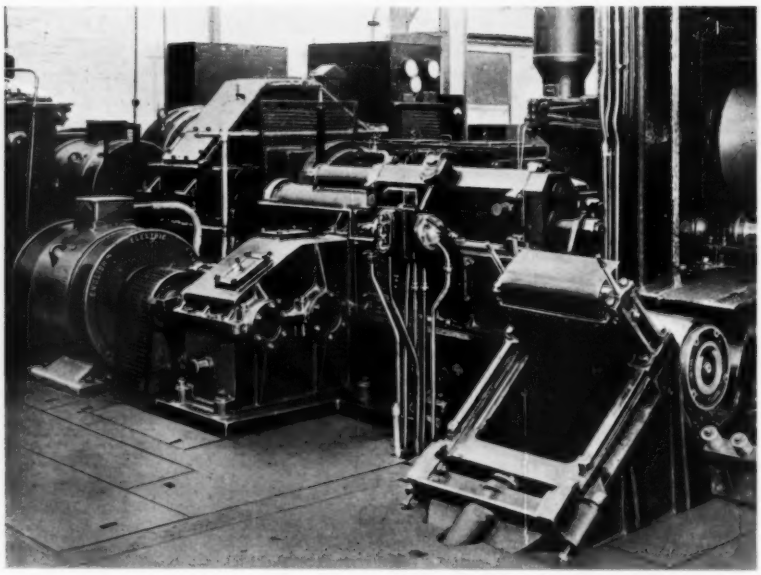


Fig. 1.—30 H.P. Constant-tension Reel Drive on a Four-high Non-reversing Reduction Mill for non-ferrous strip, driven by a two-speed A.C. Motor.

therefore unless the clutch adjustment is continuously changed, the tension will vary. This variation is not so apparent with a small build-up on the reel, say 20 per cent. or so, but where the build-up is likely to be much greater than this, then for consistency in gauge of strip it is essential to obtain a more constant tension: means for automatically obtaining this by electrically-driven reels have, therefore, been developed.

Mechanically-driven reels must be geared to the mill so that they tend to be driven at a peripheral speed in excess of that of the mill in order to secure adjustment of the slipping clutch to give the required tension. There is also an increasing dissipation of heat in the clutch and brake linings during a pass which places a limit on their size and results in constant wear and renewal of these linings.

Mechanically-driven reels have the advantage over electrically-driven reels of being driven at speeds inherently proportional to the mill, whereas electrically-driven reels have to be specially controlled to achieve this result.

Electrically-driven constant-tension reels, despite their extra complication and cost, are universally employed for large reels and are now being used much more than hitherto for smaller reel drives. This is due to the constant tension attainable, the greater flexibility in operation, and to the fact that the operating tension can be controlled so conveniently from a cabinet on the mill housing or from a separate control desk. (See Figs. 2, 3, 5 and 7.)

Where close accuracy of gauge is required, a "flying micrometer" which continuously indicates the strip gauge as it leaves the mill is a valuable addition to an electrically-controlled tension system. By employing such an arrangement, the gauge can be controlled within fine limits by manual control of the tension, using the micrometer as an indication as to whether the tension should be increased or decreased.

Even the simplest electrical automatic constant-tension winding reel drive will give the following controls:—

(*a*) Movement of the reel in either direction, whether the mill is revolving or at rest.

(*b*) Tension applied or tension released at will.

(*c*) Constancy of tension during the build-up within an accuracy of plus or minus 3—7 per cent. of mean tension with a build-up of, say, 2 : 1.

(*d*) Indication of tension obtained, on an instrument.

(*e*) Braking of the drum reel and coil to rest, independently of the operation of the mill.

(*f*) Adjustment of required tension and operation of the above points by means of push buttons or control switches mounted conveniently (shown in Figs. 5 and 7).

Fig. 2.—Reel end of three electrolytic steel-strip cleaning lines.

Additional features which can be conveniently obtained with electrically-driven reels are as follows :—

(*g*) A very wide range of tension control from the maximum down to practically zero tension.

(*h*) Tension retained at stand-still or so-called "stalled tension."

(*j*) Inertia control to minimise the disturbance of tension during acceleration and deceleration.

(*k*) Drag or back tension on strip entering the mill without or with stalled tension.

(*l*) Reversibility in operation carried out from a desk, either without stalled tension where the strip is rolled up to the mill at each pass, or retaining

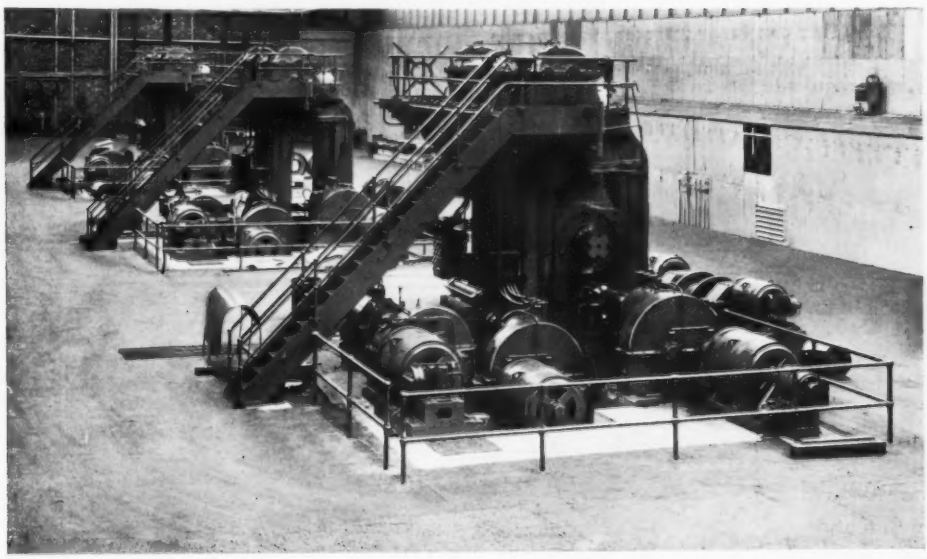


Fig. 3.—Three Four-high Non-reversing Temper-pass Mills with electric tension drives.

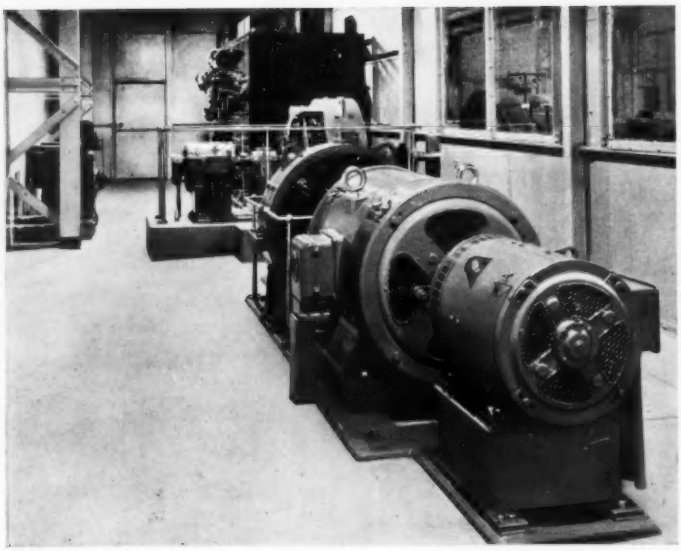


Fig. 4.—100 H.P. Mill Motor and Motor-Generator Set for a 12 in. Temper-pass Mill with a 50 H.P. constant-tension Reel Drive.

stalled tension during the changing-over in functions of the two reel drives.

As the gauge rolled is influenced not only by tension but by the rolling speed, it is desirable to have accelerating and decelerating times as short as possible. This can be arranged automatically, so saving time and strip and lessening the attention required. In fact, automatic operation of reversing mills can be arranged with combined automatic screwdown adjustment to a prearranged schedule, the mill stopping and giving an alarm at the end of the last or last but one pass.

In mills dealing with very thin material, such as foil, looping devices, which are suitably biassed to obtain a given tension in the strip, can be employed with advantage to give still finer control of the tension and to adjust the reel drives during the accelerating and decelerating periods.

With larger mills, these devices are not quite so suitable, although tension rolls have been introduced between the mill and the reels to give constant tension on either side of the mill irrespective of the winding and unwinding tensions.

Where these features are not permissible, the normal method of controlling the tension in electrically-driven reel drives is based on the principle that for a given mill speed and given constant tension, the horse-power of the reel drives must remain constant. This is carried out by inherent design in the reel motor and the generator feeding it, or by working on the basis that for constant reel H.P. and constant voltage, the current will be constant, and therefore a constant-current regulator acting on the field of the reel motor is employed.

The size of the reel motor is dependent upon various considerations, such as the maximum tension to be exerted, the maximum speed range of the reel motor and that of the mill, to-

Fig. 5.—Drag and Winding-reel Control Pedestals for an 18 in. Temper-pass Mill.

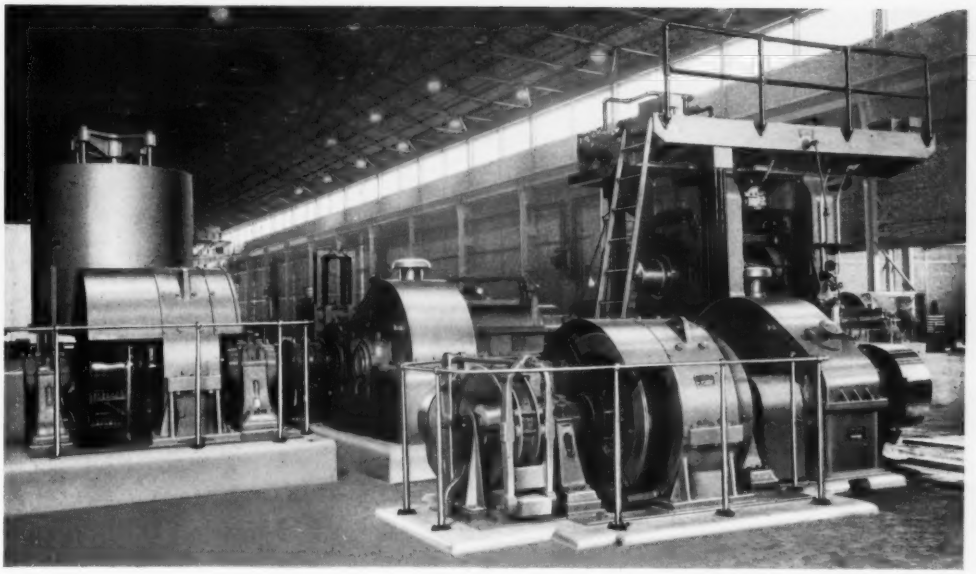


Fig. 6.—800 H.P. Main and 150 H.P. Reel Drives for a Four-high Reversing steel-strip Reduction Mill.

gether with the effect of the control arrangements. For example, the speed range of a reel motor must provide for variation in speed of the mill, the coil diameter variation, wear of rolls, and a control margin, while on the unwinding reel an additional range of speed is required, since the strip will enter the mill slower than it leaves the mill, *i.e.*, if a 30 per cent. draft be taken on the mill the unwinding reel will run 30 per cent. slower than the winding reel.

A further important requirement is that the reel motor should have an armature of low inertia, and, in all medium and large reel motors, this results in such machines being of the forced-ventilated type.

Examples of Cold Strip Mills.

An example of a simple non-reversing mill with a constant winding tension drive is shown in Fig. 1. The mill has a two-speed electric drive, the reel being driven by the separate motor shown on the left-hand side, and equipped with belt wrapper, etc., in the usual way. This is an example of what may be called the inherent system of constant-tension control, the design of the motor and its generator being such that over the reeling period the horse-power remains constant within close limits for a given mill speed, but again is proportionally increased for a higher mill speed.

Fig. 7.—Control Desk for the Reversing strip Mill shown in Fig. 6.

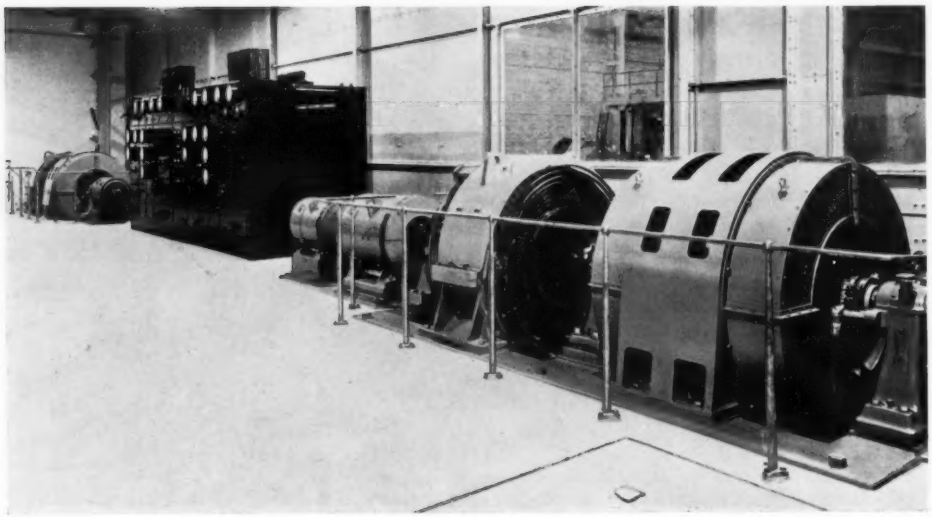


Fig. 8.—Two 1,400 H.P. synchronous Motor Generator Sets and set-up control gear for two Reversing steel-strip Mills.

Strip coiling under constant tension control by means of a current regulator is shown in Fig. 2 where three reel drives are illustrated with their control desks at the end of a steel-strip electrolytic-cleaning line. The strip, of tin-plate gauge, is cleaned by electrolytic means after having been reduced in gauge through a tandem mill, this cleaning being necessary before the further annealing process.

The driving motors are of 75 H.P. each, and were already existing when applied to this drive. The motors are fed from a Ward Leonard motor-generator set and give constant, but adjustable tension when reeling at speeds up to 800 ft. per minute on a reel of 20 in. diameter, built-up to a coil 50 in. diameter, and operating against drag rolls coupled to a 50 kW. drag generator.

In Fig. 3 are shown three mills of the four-high non-reversing type for temper or skinpass rolling. Each mill is equipped with cones carrying the coil, with attached generators to give back-tension, a pair of tension rolls to give constant tension in the strip when leaving the rolls, and an electrically-driven tension reel for winding purposes.

These mills are of great interest since their duty requires them to work over very great ranges of tension and, since the draft in such a mill is obviously very small, the main mill motor of 150 H.P. is often actually generating power, which is returned to the system via the main generator.

The two drag-tension generators are of 25 kW. each. The tension-rolls are driven by a 150 H.P. motor and the winding reel by a 100 H.P. motor. Speeds of up to 1,000 ft. per minute are obtained, the build-up of the coil being similar to the above-mentioned cleaning line, *i.e.*, build-up from 20 in. to 50 in. on the winding reel.

Fig. 4 shows the motor-house of another non-reversing temper-pass mill of the 12 in. two-high type, which is equipped with a 100 H.P. mill motor and a 50 H.P. motor driving the constant-tension drive on the winding reel. The compartment holding the motors and motor-generator sets with switchgear, is located under the crane rails and therefore takes up little space, while two more drives for 18 in. mills with constant-tension drives and drags are also contained in an extension of this house.

A typical example of the control of an 18 in. temper-pass mill, with winding and drag reels, as carried out from two control pedestals, is illustrated in Fig. 5.

A reversing strip-mill drive applied to a four-high mill dealing with steel strip up to 20 in. wide at speeds up to 800 ft. per minute, is shown in Fig. 6, the main drive being of 800 H.P., while each reel motor is of 150 H.P. and of the forced-ventilated type, equipped with magnetic brake.

The control of the whole of this mill drive, with its screwdown gear, is carried out from two control desks placed on the operating side of the mill, one desk being shown in Fig. 7.

The electrical supply to two of the above mills is obtained from two motor-generator sets which, together with the setting-up control panels, are shown in Fig. 8.

The Fundamentals of Steam Turbine Governing.

By H. G. YATES, M.A., Turbine Research Engineer, Steam Turbine Department.

The care taken in the design and manufacture of the governing mechanism used on " English Electric " steam turbines has established their reputation for good governing, and has enabled this reputation to be maintained in spite of the more difficult governing conditions which have arisen of recent years.

After reliability the essential requirement of a good governing mechanism is stability, or freedom from hunting. The precautions necessary to fulfil this requirement have latterly been extended by the general increase in operating steam pressures, particularly where specialised types such as high-pressure superposed turbines and certain classes of pass-out machines have been used. These developments have led to renewed attention being given to the whole subject of steam turbine governing in order that the present satisfactory position shall be maintained, even under the most arduous conditions and with the most specialised types of turbine likely to be encountered in practice.

Consideration of governing characteristics should be preceded by an understanding of the fundamental relations of power systems, and in this article it is proposed to examine such problems from first principles with particular reference to the factors which influence the requirement already stated, namely stability.

Before considering the effect which any given type of governing gear may have on the stability of the whole system, it is necessary first to examine the inherent stability of that portion of the system comprised in the combination " prime mover plus load." To do this, the prime mover and the type of load must each be considered from the aspect of torque-speed and power-speed characteristics.

Dealing first with the prime mover, there are in general two types of torque-speed characteristic ; one, which will be called Class A, in which the torque is constant (to a first approximation) at all speeds, and another, Class B, in which the torque falls steadily as the speed increases, for a given setting of the control mechanism. Fig. 1 shows, on the left, the torque-speed characteristic, and on the right the corresponding power-speed characteristic for each of the two classes. Since the power produced is equal to the product of torque and speed, the power curve for Class A is a straight line radiating from the origin as shown. In the case of Class B the power first rises, reaches a maximum at half the maximum speed, and then falls. The curve is a parabola.

It must be clearly appreciated that the above theoretical curves apply solely to a machine operating without any form of regulation. The controls are assumed to be fixed in a given position, and the speed to be varied merely by variations in the applied load.

No actual prime mover corresponds exactly to either of these simple theoretical types. Due to secondary effects, arising from one cause or another in an actual design, there are departures, often considerable, from the simple curves of Fig. 1, but nevertheless the broad division into two classes remains.

For example, a reciprocating steam engine belongs basically to Class A. Due principally to wire-drawing in the valve ports, the steam has not free access to the cylinder at high speeds, and

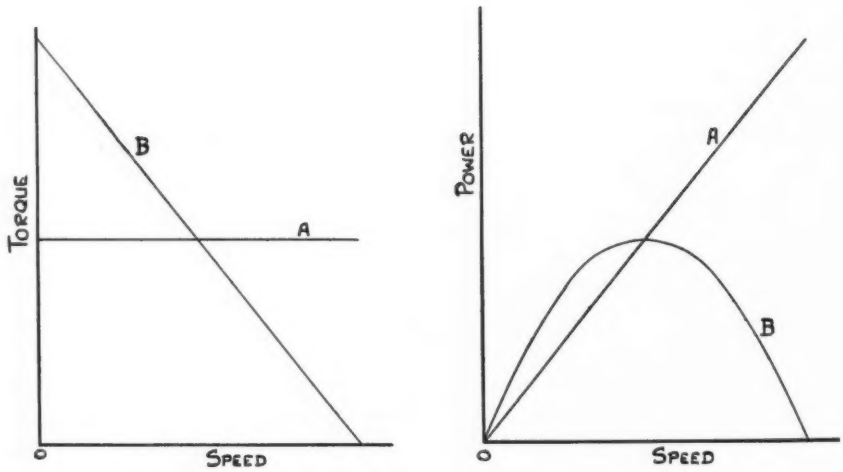


Fig. 1.—Theoretical characteristic curves of ungoverned Prime Movers.

the torque tends to fall with rise in speed, as depicted by curve *a* of Fig. 2. An internal combustion engine also falls into Class A, but in this case there is at low speeds a reduction in the turbulence necessary for efficient combustion, and also a reduction in the maximum pressure reached in the cycle. The curve therefore rises slightly with increasing speed at low speeds and then droops again, as shown by curve *b*.

Perhaps the best example of a Class A prime mover is the well-known Hero's turbine, illustrated in Fig. 3, in which the steam is generated inside the rotor and allowed to expand through tangentially-directed nozzles to the external atmosphere. Such a machine has never been constructed on a large scale. In a turbine of this class windage is the only factor which causes a fall in torque at high speeds, and the torque curve is very flat over a wide range of speeds.

Prime movers of Class B are perhaps best represented by a water-turbine of the Pelton wheel type. When the water nozzles are running at full pressure, the torque is proportional to the relative speed of water and buckets. It therefore falls linearly as the speed increases. A steam turbine belongs in the main to Class B, and its torque-speed characteristic is shown approximately by curve *a* of Fig. 4.

Another example of a Class B machine is afforded by a D.C. electric motor of the series type, particularly in the region of magnetic saturation at low speeds. Such a motor is not usually classed as a prime mover, but a typical characteristic is shown roughly by curve *b* of Fig. 4 for comparison purposes.

An essential difference between the two classes of prime mover is of some interest. The runaway

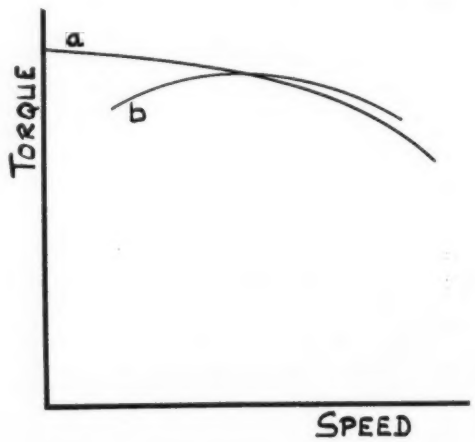


Fig. 2.—Approximate ungoverned characteristics of (a) Steam Engine and (b) Internal Combustion Engine.

Fig. 3.—Model of Hero's Turbine, about B.C. 120.

speed of Class A machines is very high, being infinite for the simple theoretical case. (Internal combustion engines lose their Class A characteristics at high speed, for a variety of reasons, and their torque eventually falls abruptly, so that a limiting speed is soon reached.) Class B machines, on the other hand, have a very definite speed limit which cannot be exceeded if all load is thrown off, even in the absence of a governor. This limiting speed is the speed at which the torque falls to zero, and is theoretically twice the speed for maximum output. The latter, while not necessarily the designed operating speed, is usually so in practice. For instance, a high efficiency steam turbine generally operates at or about the peak of its power-speed characteristic curve (see Fig. 1). On the other hand, a single-stage turbine such as is sometimes installed to supply power station auxiliaries in emergency, may quite well operate far below the peak of its power curve. In theory, therefore, it might run up to three or four times normal speed if all the load were removed and the steam supply were not cut off very quickly.

Turning now to the torque-speed characteristic of the load, it is again convenient to group machines according to the nearness with which they approximate to a few simple theoretical types. The first type, referred to as Class A by analogy with the same class of prime movers, is exemplified by the Prony brake. The torque in such a brake is purely frictional, and is very nearly constant for all but extremely low speeds.

Class B has a linearly rising characteristic, similar to the uniformly falling characteristic of a Class B prime mover, and is closely approximated by a permanent-magnet D.C. generator connected to a resistance load. As the speed rises the E.M.F. rises almost proportionally and drives a linearly rising current through the total resistance offered by armature and external resistance. The power taken thus varies as the square of the speed, and the torque is a linear function of the speed.

A further type of load frequently encountered, referred to as Class C, is one in which the torque

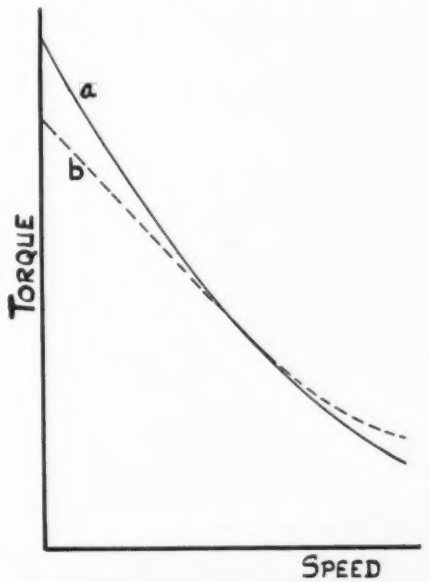


Fig. 4.—Approximate ungoverned characteristics of (a) Steam Turbine and (b) D.C. Electric Motor.

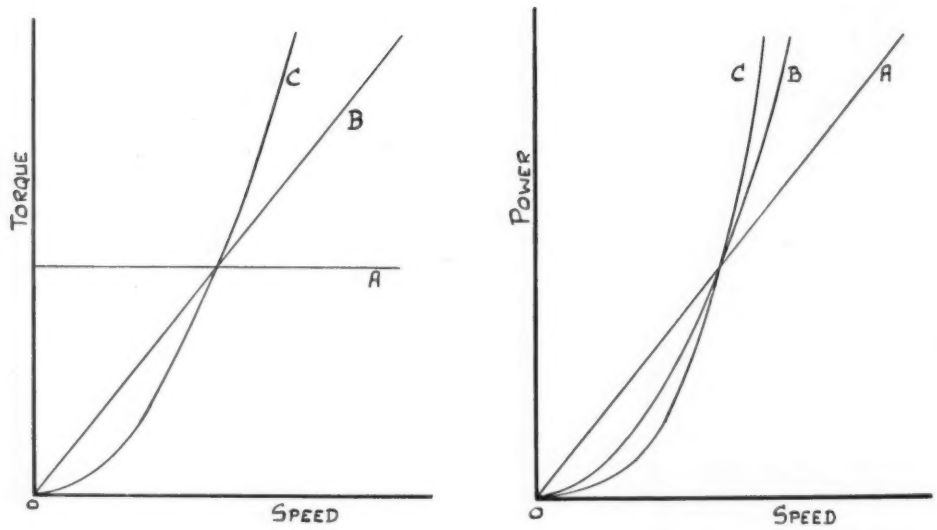


Fig. 5.—Theoretical characteristic curves of Driven Machines.

rises proportionately to the square of the speed, the power taken varying as the cube of the speed. This is the case, for instance, with a turbo-blower delivering air to an orifice of given size.

The torque-speed and power-speed characteristics of the three classes are shown in Fig. 5.

The next step in the investigation is to combine the foregoing characteristics. Consider the hypothetical case of a prime mover running on load without a governor, the controls being fixed in a predetermined position. The speeds of driving and driven shafts are necessarily the same and the torque supplied by the prime mover is just equal to the torque demanded by the load.

Suppose now that, although the load conditions remain constant, the speed falls slightly. The driving torque will change slightly, as will the torque required to turn the driven machine. If the prime mover is now supplying a smaller torque than that demanded by the driven machine at the new speed, the speed will fall still further, and the system is therefore unstable. This condition is shown graphically in the left-hand diagram of Fig. 6.

If on the other hand the prime mover torque at the lower speed is greater than the torque required at that speed by the load, as shown on the right in Fig. 6, the excess torque will be in the correct direction to cause an increase in the common speed of the two shafts. It will therefore tend to neutralise the small drop in speed which has been presumed to take place, and the system is consequently stable.

It is fortunate that nearly all the possible combinations of prime mover and load satisfy the above conditions for stable operation. For example, a steam turbine (Class B) with its falling torque-speed characteristic will be quite stable when driving a Prony brake (Class A) with its constant torque. It will be extremely stable when driving a turbo-blower (Class C), with its rapidly rising characteristic, particularly at high speeds.

On the other hand, a prime mover of Class A driving a Class A load is of somewhat uncertain stability. If the class conditions are very precisely satisfied and the driving and driven torques are exactly constant, the equilibrium will be neutral ; that is to say, a small increase in speed will persist, neither increased nor decreased, until either the load or the prime mover controls are altered. Consider however an internal combustion

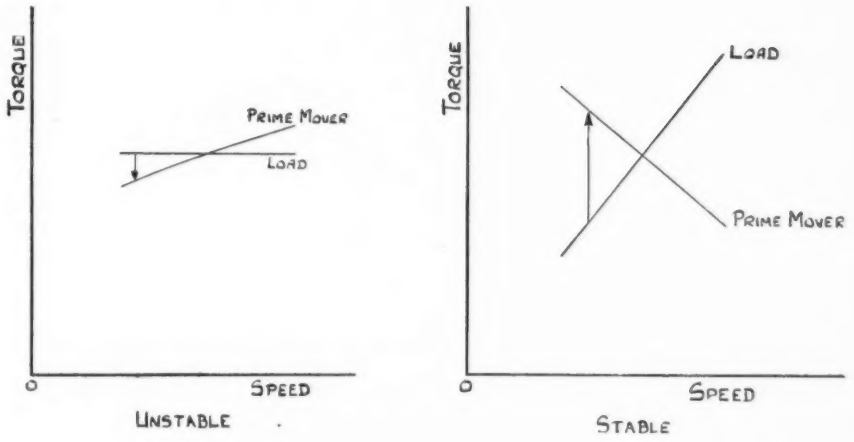


Fig. 6.—Diagram illustrating stability of ungoverned system.

engine driving a Prony brake. If the engine is working at the peak of its torque-speed characteristic (curve *b* in Fig. 2), the equilibrium will be neutral. If it is operating at a higher speed the system will be stable. If, however, it is operating below the peak of the curve, that is at a small proportion of the maximum load corresponding to the particular setting of the fuel control, the system will be unstable. This is not to say that it cannot be made reasonably satisfactory with a good governor, but the speed will continually fluctuate over a small range determined by the sensitivity of the governor.

The above considerations relate only to ungoverned power systems, and they will be radically altered by the introduction of a governor control mechanism. The governor itself is provided to record any change in speed, and through its associated governor gear to operate the controls in such a way that any torque within the capacity of the system may be provided without more than a specified small amount of speed variation.

The operation of a governor-controlled system is shown graphically in Fig. 7. The example chosen relates to a Class B prime mover, to which class a steam turbine belongs, and a Class B load has also been assumed.

In Fig. 7 (a) the lines *a*, *b* and *c* are the ungoverned torque-speed characteristics of the prime mover for three different settings of the control mechanism, and *x*, *y* and *z* are the corresponding characteristics of the load. In Fig. 7 (b) the corresponding power-speed curves are drawn. Lines *a* and *x* relate to full load, and *c* and *z* to no load beyond internal friction in the driving and driven machines.

The design of the governing mechanism is such that at a speed corresponding to M in Fig. 7 (a), the controls are automatically set in the position required to produce the driving torque corresponding to P, and at speed N they are set to produce the torque corresponding to Q. Intermediate torque values will be obtained at intermediate speeds in the range MN, which is the total governing speed variation.

The total governing speed variation MN is normally quite small, though it has been greatly exaggerated in the figure for greater clarity. The line PQ has consequently a very steep slope, and from considerations similar to those dealt with previously in connection with Fig. 6 it will be clear that the slope must be *downwards* from left to right in order to achieve stability. In other words, the speed change from full load to no load positions of the governor head must be in the direction of increasing speed.

Governors have been made in which the change

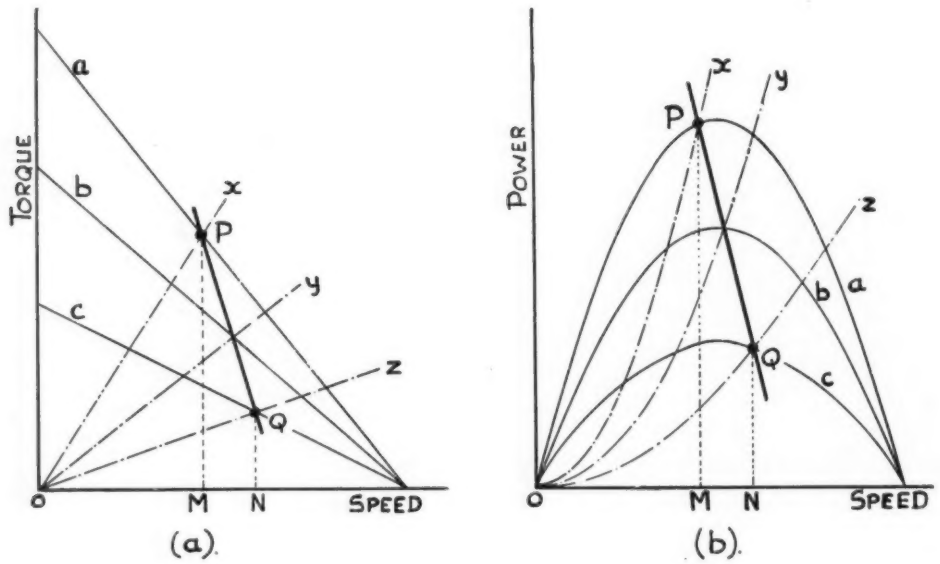


Fig. 7.—Theoretical characteristic curves of typical governed system.

of speed from full load to no load is zero, and are known as isochronous governors. These are not in themselves stable, though they may be made so by internal mechanism which introduces a temporary speed change, operative while a change in load is taking place and thereafter fading out gradually.

The power-speed characteristics of a governed Class B prime mover, indicated in Fig. 7 (b), show how the governor selects the appropriate ungoverned curve to suit any given load, and it is interesting to note that the operating point is automatically maintained at or near the peak of the curve. The efficiency of operation is thus always at or near the maximum obtainable under the particular load conditions which exist at a given instant.

The next requirement of a governor is a suitable degree of sensitivity ; that is to say, the speed change from full load to no load must be suitable for the type of load. For a turbine driving a blast-furnace blower, high sensitivity is unnecessary. On the other hand, a machine supplying A.C. power to a woollen mill employing synchronous motors must keep the frequency very nearly constant, and a high degree of sensitivity is called for.

Rapidity of response is another requirement in a good governor, particularly so in the case of a large back-pressure turbine whose power is great in proportion to the inertia of its rotor. Here a fall in load will result in a rapid acceleration of the shafts and the governor response must be proportionately rapid.

Finally a good governor should be as free as possible from friction and back-lash. A system with an appreciable amount of governor friction may yet be stable, if the rest of the system is sufficiently far removed from instability, but the less friction present the easier is the task of obtaining stable operation.

A detailed discussion of the characteristics of different types of governors is outside the scope of this article, but it will be appreciated that almost any mechanism which is responsive to a change of speed can be employed. The most commonly used is a mechanical type in which a revolving weight forms the speed-responsive element. Hydraulic governors, in principle similar to a centrifugal pump, have been used with

success. A good governor could also be made of an electric generator whose voltage would be a measure of the speed, and this has also been used for particular types of speed control.

No less important than the governor is the governing gear which transmits the indications of the governor to the controls. This gear varies considerably both in principle and in detail on different types of prime mover and even between different makes of steam turbine, and whilst the foregoing remarks have been of general application, except where otherwise indicated, it is now proposed to deal particularly with the most usual form of control gear fitted to modern steam turbines.

Formerly turbine governors were frequently direct acting, operating the control valves by simple mechanical means. Large machines, however, require considerable power to move the steam valves and furthermore the power of a governor decreases as its sensitivity is increased. Modern conditions of large machines and very close speed regulation therefore demand some form of power relay, and this is generally of a hydraulic type.

A typical arrangement is shown diagrammatically in Fig. 8. The operating sleeve of the governor G is linked to the spindle of the main control valve V by a lever L. The stem of a pilot valve P is connected to L at a suitable point. Oil under pressure is admitted to the pilot valve as shown by the arrow. When the pilot valve is in the neutral position it covers each of two ports which connect with the top and the bottom respectively of a relay piston R, connected to the spindle of the main steam valve V.

Should the turbine speed rise slightly, due to a reduction in load, the governor responds almost instantaneously and raises the end of lever L, carrying with it the pilot valve P. Oil therefore flows to the upper side of relay piston R at a rate determined by the supply pressure and the lift and size of the pilot valve. The relay piston moves downwards at a rate dependent upon its area and upon the rate of oil flow, forcing out an equal flow of oil through the lower port of the pilot valve. By the movement of the relay piston the main control valve V is closed slightly and the rise in speed is therefore checked. The system finally comes to rest with the pilot valve once more in the neutral position, the control valve V slightly less open than at the beginning of operations, the governor sleeve slightly higher and the turbine speed slightly increased.

Treated analytically such a governing gear calls for a somewhat elaborate mathematical investigation in order to determine whether the whole system will be stable under any given operating conditions. This investigation covers, besides the rates of response of the various moving parts, such factors as governor sensitivity, governor damping, rotor inertia and the rate at which the steam flow responds to movements of the main control valve. In practice the wealth of experimental and operational data available to established manufacturers makes this procedure unnecessary in any but very special cases, and one of these cases which has come into prominence since the employment of very high steam pressures deserves special mention.

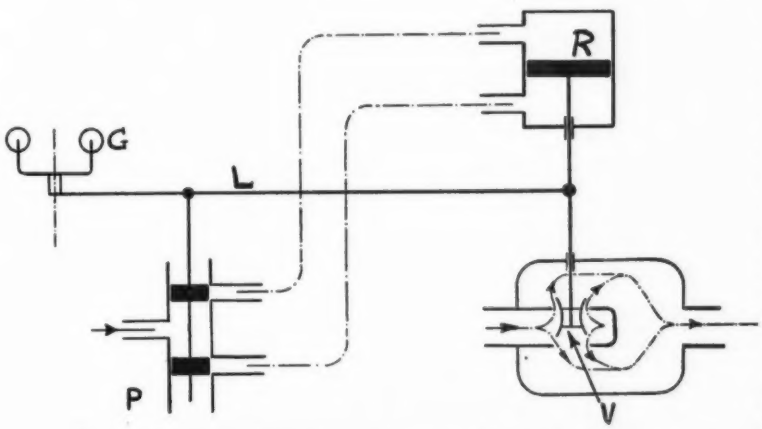


Fig. 8.—Diagrammatic arrangement of typical Relay-operated Governing Gear for Steam Turbine.

If the control valve were immediately in front of the first stage nozzles of the turbine, the steam flow through that stage would instantaneously follow the movement of the control valve ; and since a particle of steam takes only one or two tenths of a second to make its way right through the turbine to the condenser, the steam flow throughout the machine would very quickly settle down to its new reduced value ; the driving torque would follow suit, and the speed of rotation would follow at a rate dependent on the inertia of the rotors. In practice, however, there is an appreciable volume of storage space between control valve and nozzles, mainly in the connecting pipes from the steam chest to the turbine.

The curves in Fig. 9 demonstrate, for a hypothetical case, the effect of this storage space upon the steam flow through the machine. At the commencement the control valve is assumed to be completely closed. It is then opened gradually at a constant rate. Neglecting a slight curvature in the very early stages, the rate of steam flow would, if there were no storage space, rise uniformly as shown by the straight line *a*. When the storage volume is taken into account, the flow would follow curve *b*, rising slowly at first and then approximating to a straight line parallel to *a* but displaced a certain distance to the right. This distance may be found by calculating the time taken to empty the storage space if the valve were suddenly closed and if it were possible for the stored steam to flow out through the turbine at a constant rate equal to the rate obtaining when the valve was closed (actually the rate of outflow would fall as the pressure in the storage space falls and the time for complete emptying would theoretically be infinitely great).

The volume of storage space in most cases is not great, and its influence on the stability of the system, though adverse, is small. But occasionally a special machine may present a new problem.

A case in point is a pass-out turbine designed to handle a quantity of pass-out steam which is very large in proportion to the designed condenser steam flow. When starting up, the pass-out main is closed. The steam flow required to run the turbine light may be so small that it " trickles " through the high-pressure portion, which is designed for a flow perhaps fifty times as great, and is not " held " until the first of the low-pressure stages is reached after the pass-out point. The whole of the high-pressure portion is virtually storage-space, and a normal governor gear may be rendered unstable unless special precautions are taken. These precautions would aim at increasing the rate at which the main control valve responds to the indications of the governor. In the type of gear referred to above, probable modifications would include increasing the size of the pilot valve, and increasing its rate of travel by altered lever ratios or the inclusion of a magnifying linkwork. In addition the sensitivity of the governor might have to be reduced, since the governing speed variation from maximum to minimum load at a fixed pass-out quantity may be only a fraction of the total speed variation when changes in pass-out quantity are taken into account.

There are other problems connected with the governing of steam turbines, in particular some special considerations which affect the governing of machines running in parallel, but these again are outside the scope of the present article. The function of a governor on a turbo-alternator set feeding into a large A.C. network, however, should be recognised, as it does not govern in the generally accepted sense of the word.

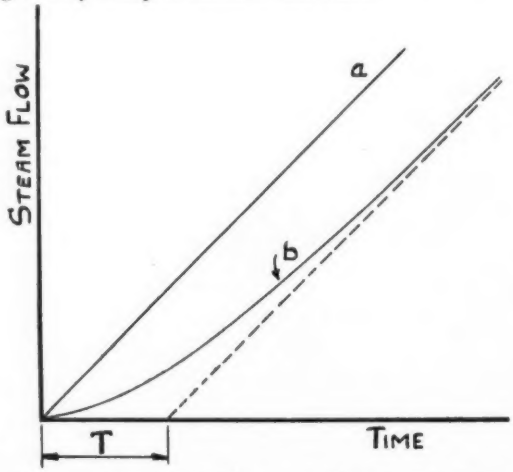


Fig. 9.—Diagram illustrating steam flow control in Steam Turbine with storage space between Control Valve and Nozzles.

The speed of the turbine in such a case is ordinarily fixed by the frequency of the electrical network. This frequency necessarily varies when changes of load occur, but with a very large electrical system the change in frequency caused by a total load change equal to the full output of the machine under consideration is very small. A single machine might, therefore, be permitted to feed into such a system without being governor-controlled, provided that the remaining machines are governed and that the total load on the system is always much greater than the load carried by the ungoverned machine. In practice a governor is always fitted, even on base load plant, so that the system frequency shall not rise excessively even if all load is removed.

Assuming for the moment an ungoverned machine operating in parallel with such a system, at a fixed setting of its control valves, the relative phase of generator and network will adjust itself so that the fixed output of the turbine is absorbed into the system. If the control valves are opened slightly the turbine speed will increase momentarily and, after a few slight variations up and down, will settle to a speed practically identical with its former value when the necessary adjustment to the phase has been made.

When a governor is fitted to such a machine, as is always done in practice, its primary function of regulating the speed becomes of secondary importance and instead the governor becomes a load regulator. Every governor is fitted with a hand or remote-operated speed control by which the speed of the machine, if free from external control, can be varied by a predetermined amount. This functions by varying the steam-valve lift corresponding to a given position of the governor head. Consequently when the speed is fixed by the external network, the speed control is used to vary the output of the machine at a given speed instead of varying the speed for a given load.

The solution of steam turbine governing problems is sometimes a difficult task, but the modern trend towards the use of higher steam pressures and special machines, whilst tending to accentuate the difficulties, can be effectively dealt with provided a clear conception of the fundamental principles involved is obtained, accompanied, of course, by a suitable degree of accuracy in manufacturing the various components concerned.

Arc Furnace Transformers.

By C. C. McLAREN, B.A.(Eng.), A.M.I.E.E., Transformer Sales Department.

For many years the mention of Electric Arc Furnaces was immediately associated in the minds of Engineers and Industrialists with the large-scale production of cheap electric power—naturally by hydro-electric schemes—and with particular reference to the dry electrolytic process of manufacture of aluminium and similar non-ferrous metals. This attitude was based on the somewhat arbitrary (and since proved unfounded) assumption that to consume electrical energy except in rotating plant, and especially in reversion to heat energy as in an electric arc, was wasteful of the efforts of producing this fluid and flexible means of conveying and distributing power over a wide area about a central generating point. The efforts of a small body of Engineers who have devoted themselves assiduously over a number of years to the problems associated with the effective application of this simple means of resolving electric power into heat, backed by certain manufacturers interested in the production of high-quality steels, have now brought the Steel Melting Arc Furnace to a pitch where it seriously rivals the Open-Hearth and other combustion types of furnace for this purpose. It is now recognised that the close metallurgical control of the constitution of the steel produced, coupled with an aptitude not shared by any combustion furnace, for the bulk consumption of scrap, renders the installation of such plant a fully justifiable economic proposition even where electric power is only

available at the somewhat higher costs represented by its production from steam coal.

The present urgent demand for high-quality steels for the construction of armaments and aircraft has indeed given an impetus to the steady advance of this valuable apparatus to its rightful position in the organisation of the Steel Industry, and the number of arc furnace plants now installed or in process of installation has reached a figure which would have startled the more conservative minds among the Steel Manufacturers or the Electrical Engineers of a few decades ago.

While, therefore, it is realised that the application of the arc furnace is by no means restricted to the production of steel, this particular facet of its versatility would seem to have sufficient scope of interest at the present time to justify confining the range of this article to a consideration of Steel-Melting Arc Furnace Plant only.

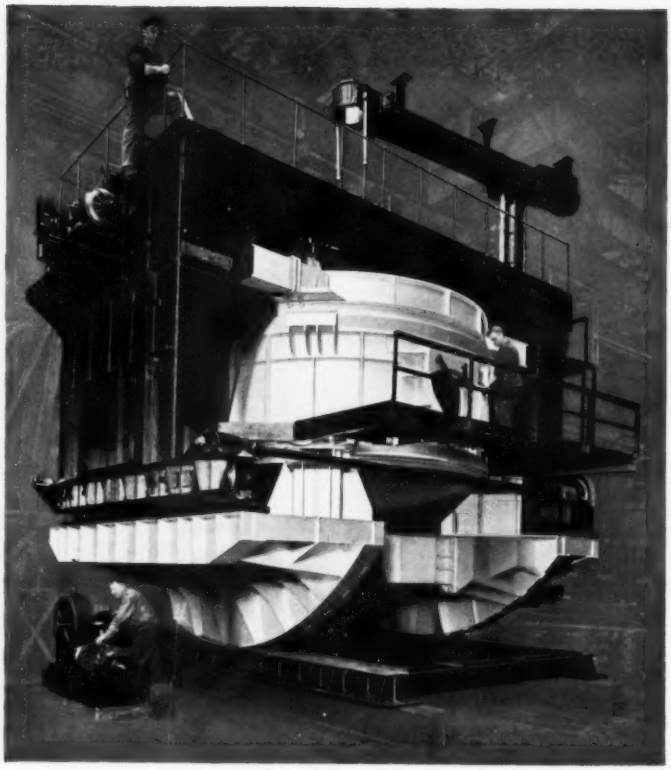


Fig. 1.—A modern 15-ton Steel-Melting Arc Furnace in course of construction.

The process of manufacture of steel in an arc furnace is fundamentally no different from that which takes place in a combustion furnace, that is to say : the process depends upon the passage of the constituents through a controlled heat-cycle, the electric furnace having, however, the great advantage already mentioned, namely, that a much closer control of the metallurgical constitution of the finished steel is possible, due to the elimination of the intimate contact between the fluid metal and the products of combustion that is inevitable in furnaces of the other type. Thus, as opposed to the general case of the production of non-ferrous metal by the electric arc, where the directional nature of the flow of current is an essential feature of the electrolytic analysis of the raw material into its constituents, it is possible with the steel-melting arc furnace to employ *alternating current*. Furthermore, by the use of an appropriate number of electrodes and a suitable design of the furnace, the polyphase systems normally available for the delivery of large quantities of electric power can be utilised to full advantage with the offer of approximately symmetrical loading on all phases.

The implications of this open choice are immediately obvious, and it at once becomes clear that the flow of power to the furnace may be controlled by the usual static methods peculiar to the use of alternating current, that is to say, with transformer equipment.

The investigations carried out by the pioneer builders of steel-melting arc furnaces soon showed that the required power must be fed to the furnace in the form of a relatively heavy current at a fairly low voltage, this being determined by the

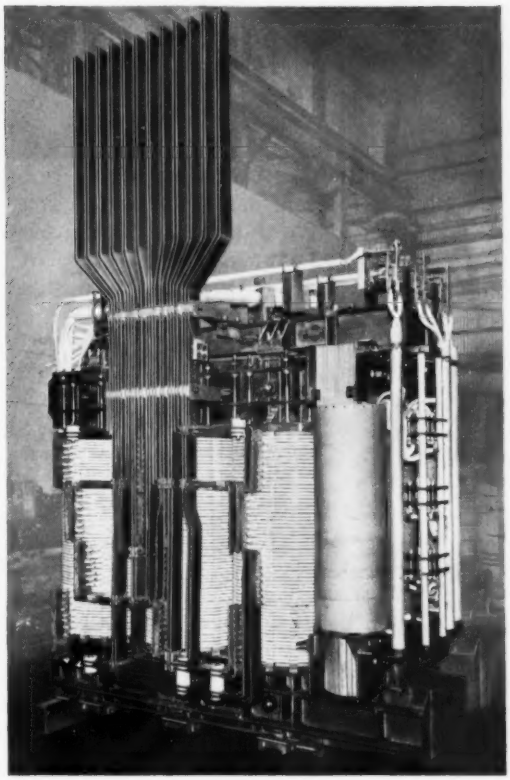


Fig. 2.—The Core and Windings of the 6,000 kVA. "English Electric" Transformer for feeding the furnace shown in Fig. 1; showing H.V. Series Choker mounted across the end of the Main Core.

characteristics of the arc itself and by considerations of the behaviour of the parts of the furnace exposed to electrostatic stress under high temperature conditions. The fine control of the current flow was effected by the simple and well-known method of adjusting the length of the arc, but it also proved desirable to have a coarse control of the power input by regulation of the voltage. At the present day there is not yet complete accord between the opinions of Furnace Designers as to the optimum currents and voltages for the obtaining of specific results, but there is a broad generality of agreement between the requirements stipulated for the transformers, which indicates the progress that has been made towards the reduction of the problem to terms of exact science.

Thus it now is common practice for the specification of a transformer to suit such a furnace, to include for variation of the secondary voltage between the limits of $2\frac{1}{2}$-3 : 1 in a number of steps, generally at constant current, so that the power input to the furnace may be adjusted over a fairly wide range to suit the various stages of the heat cycle to which it is desired to subject the material in the furnace. The heavy secondary current usually determines that the voltage variation should be effected by adjustment of the number of turns in the primary winding of the transformer, and the almost universal adoption of the three-phase system of supply permits of an immediate simplification in that it is possible to adopt with great economy, a reconnection of the primary winding of the transformer from delta to star to give an upper and a lower secondary voltage range.

The number of voltage steps necessary to give adequate nicety of control of the operation of the furnace is again a matter of choice, but from the point of view of the Transformer Designer it is desirable to keep these to the minimum and to allow the widest possible intervals between the individual secondary voltages consistent with a satisfactory control of the power, in order that each primary tapping coil may contain a sufficient number of turns to ensure a robust design. This is an important consideration, as a transformer feeding a steel-melting arc furnace is subjected during the initial period of melting down of the charge—usually scrap metal—to repeated over-currents of several times the normal rated current, due to the movement of the charge in the furnace as it melts resulting in frequent short circuits across the electrodes. Similarly, the arc may be broken at one or more electrodes by the falling away of the portion of the metal forming the other pole of the arc, and the sudden rupture of the current in the phase in question may impose further mechanical stress upon the windings of the transformer. As described later, steps are taken to reduce the magnitude of the over-currents to reasonable proportions by the addition of reactance in the circuit, but the

conditions to which the transformer is subjected are extremely severe, and particular attention must be paid to the bracing and general mechanical rigidity of design of the windings and their support from the core framework.

The selection of the available secondary voltages is achieved in a variety of ways, but on plants of any appreciable size there is an almost universal demand for a certain degree of adjustment of the voltage under the control of the Melter from his remote position at the Furnace Control Desk, to facilitate his handling of the furnace. The tappings are therefore brought to a switch driven by means of a motor-operating mechanism controlled by push buttons or by a suitable control switch on the desk.

The tap-changing switch is designed for operation off-circuit as the provision of on-load tap-changing equipment for the wide range of voltage variation usually required, as already mentioned above, would not only be a very costly proposition but would also tend to weaken the transformer windings due to the necessity of arranging for a large number of tappings at fairly close intervals. Fortunately the operation of the furnace does not necessitate the maintaining of an absolutely continuous flow of power, the heat capacity of the charge being large enough for it to maintain its temperature and molten state for quite an appreciable period after the supply has for any reason been cut off. In any case the metallurgical process requires occasional interruptions for purposes of "slagging-off" and other attention to or inspection of the charge; it is therefore no disadvantage as far as the furnace is concerned, that this form of tap-changing involves operation of the main switch controlling the supply to the plant. Indeed, the major objection to such a system was until comparatively recently that it involved frequent opening and closing of oil circuit-breakers, some of which proved unequal to a task for which they were not originally designed. The development of the Air-Blast Circuit-Breaker has now made it possible to remove another cause of anxiety from the minds of the maintenance staff responsible for the electrical equipment associated with arc furnaces.

It is the opinion of some Furnace Designers and Builders that the voltages available on an arc furnace transformer should be sufficiently numerous to enable a certain amount of experiment to be made to determine the optimum conditions of working of the furnace with the particular product and the characteristics of the electrical supply to the plant in question. It is thereafter considered important that the selection of the voltage for any specific stage of the melting cycle should be removed from the control of the Melter in order to simplify his duties and eliminate the necessity for elaborate instructions to ensure operation of the furnace at the predetermined electrical conditions. In such cases it is therefore arranged that the number of voltages that may be selected by the Melter

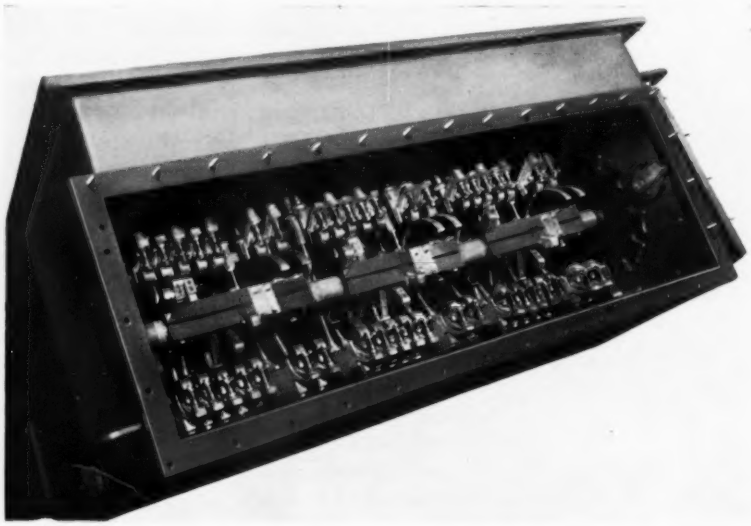


Fig. 3.—Interior of the externally-mounted motor-operated off-circuit tapchanger for the transformer shown in Fig. 2.

through the agency of the motor-operated off-circuit tap-changer, is restricted by the introduction of a system of pre-selective links between the winding tappings and the actual contacts of the tap-changer. The links are enclosed within the transformer tank and thus may only be adjusted under the supervision of a competent authority.

Opinion is now almost unanimously in favour of the housing of the tap-changing switch in a compartment separated from the transformer tank, as although the maintenance required upon the switch contacts is very small, being due solely to the effects of mechanical abrasion, the attitude of mind of Steel Manufacturers is that time is money, and a small additional capital outlay upon better class equipment is a sound investment if it ensures that a local failure, however unlikely, will thereby be limited in its effect upon the utility of the plant, and that the resultant delay until operation may again be in full swing will be minimised.

The question of maintenance must again be kept well in the foreground in considering the design of the motor-operating mechanism for the tap-changer, ease of access to the interior of the casing which must nevertheless be dust-tight, and a reasonably spacious layout of the apparatus being prominent factors in encouraging maintenance staff to give that regularity and thoroughness of attention that determine unfailing reliability and length of service with all engineering plant.

Reference has already been made to the practice of introducing additional reactance into the circuit for the purpose of limiting the current surges that occur due to short-circuiting of the electrodes during the melting stages, and there is also as an indirect result some improvement in the stability of the arc. A little consideration shows that a comparatively slight adjustment of the arrangement of the heavy current connections between the furnace electrodes and the secondary windings of the transformer, might produce a marked change in the total reactance, but this method would have the disadvantage of encouraging stray losses and once a set of conditions had been determined it would clearly be impossible to effect any variation to obtain different operating characteristics. A further objection to making a deliberate increase in reactance of the secondary circuit is that the constant ohmic value of such reactance represents a proportionally increasing percentage as the applied voltage is reduced at constant current. It is in fact usual to avoid making any deliberate increase in the reactance in this heavy-current circuit, and on the contrary, steps are frequently taken by interleaving of the busbars or equivalent methods to reduce the reactance and at the same time the stray losses, by thus improving the distribution of current in the bars. The total reactance is brought up to the necessary value by connecting a separate choker between the primary of the transformer and the incoming supply.

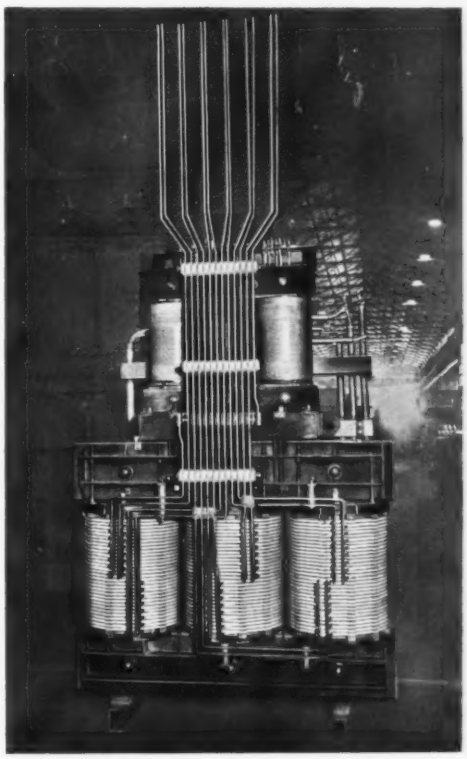


Fig. 4.—Interior of the Transformer shown in Fig. 6, showing H.V. Series Choker mounted on top of the main core.

The choker may be conveniently built as a three-phase unit on a three-limb core, which must be of the air-gapped type to provide an approximately straight-line characteristic over the range of current to be expected. Tappings are usually required to give a certain flexibility of choice to meet the conditions of operation of the furnace, and are controlled by a manually-operated off-circuit switch or by links. As compared with the case of the selection of the secondary voltages already described above, there is a very much stronger tendency to limit the Melter's choice of the amount of reactance in circuit. As a natural outcome it is common practice to associate the selection of the reactance with the selection of the secondary voltage, this being achieved by a suitable arrangement of the connections to and in the motor-operated tap-changing switch.

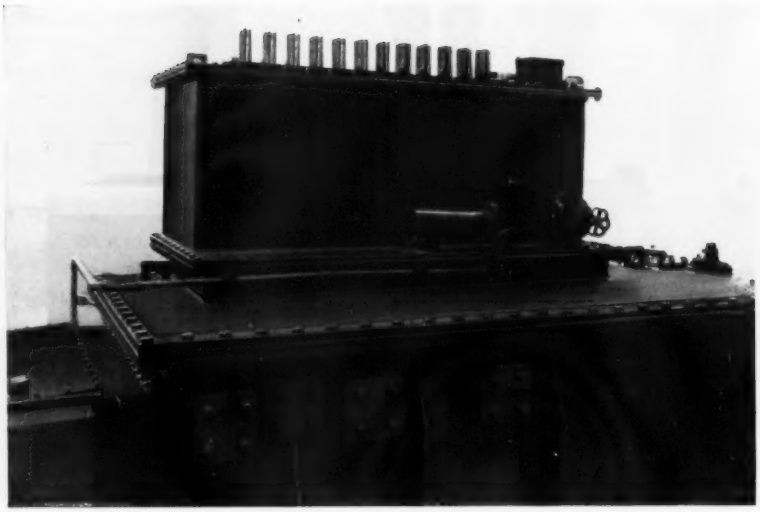


Fig. 5.—Special Expansion Vessel for Arc Furnace Transformer, showing Buchholz device.

For greater convenience in making these connections, the choker may be mounted in the same tank as the main step-down transformer, but apart from this consideration there is a strong case for adopting this arrangement in that it reduces possible sources of failure by eliminating a number of through-bushings, and a very much more compact plant may be realised. Some experienced engineers, however, are averse to this practice on the grounds that a failure in the choker, remote though this possibility may be, involves the shutdown of the complete furnace plant, whereas temporary connections may be made to cut the choker out of circuit, if built as a separate self-contained unit, and the furnace can, to some extent, continue to function. It is undoubtedly a fact that furnaces have been operated in this manner even including the melting of scrap charges, but it is well to bear in mind that the success of such an experiment must to a large degree depend upon the supply system being of a calibre such that it is not appreciably disturbed by the enhanced current surges. The choker, if soundly designed, is of such a robust character that the likelihood of failure is no greater than of failure of the transformer itself, and the general acceptance of the convenient combined equipment would seem to justify a continuance of that construction except where the purchaser expresses a definite preference to the contrary.

It is cause for considerable satisfaction that there is now an almost universal demand for the equipping of steel-melting arc furnace transformers with Buchholz devices, implying, of course, the fitting of expansion vessels. The merits of the Buchholz device for the protection of such transformers cannot be too highly stressed, as the widely variable voltage ratio and the heavy secondary current preclude the application of the usual Merz-Price or similar sensitive differential-current protection. The Buchholz device is in fact the only device sensitive to interturn failures and the protection so afforded should result in the detection of an incipient breakdown, giving the opportunity for a repair

of a simple and speedy character and perhaps preventing a major breakdown with a serious loss of the productive capacity of the furnace over a lengthy period.

The fitting of an expansion vessel normally entails the forming of oil-tight joints around the rectangular bars employed for the heavy-current secondary connections, but this problem has been successfully overcome, or rather avoided, by an ingenious construction of the expansion vessel in which the vessel is formed as a chamber welded directly on to the transformer cover to embrace the vertical L.V. terminal bars. These enter the vessel from the main tank through a joint which is by-passed by a connecting pipe arranged in the usual manner for the fitting of the Buchholz device. The joint, therefore, is subjected to equal pressure on both sides and requires only to be bubble-tight to ensure the proper functioning of the Buchholz device. The bars emerge through an upper joint in the cover of the vessel, which it is only necessary to make dust-tight.

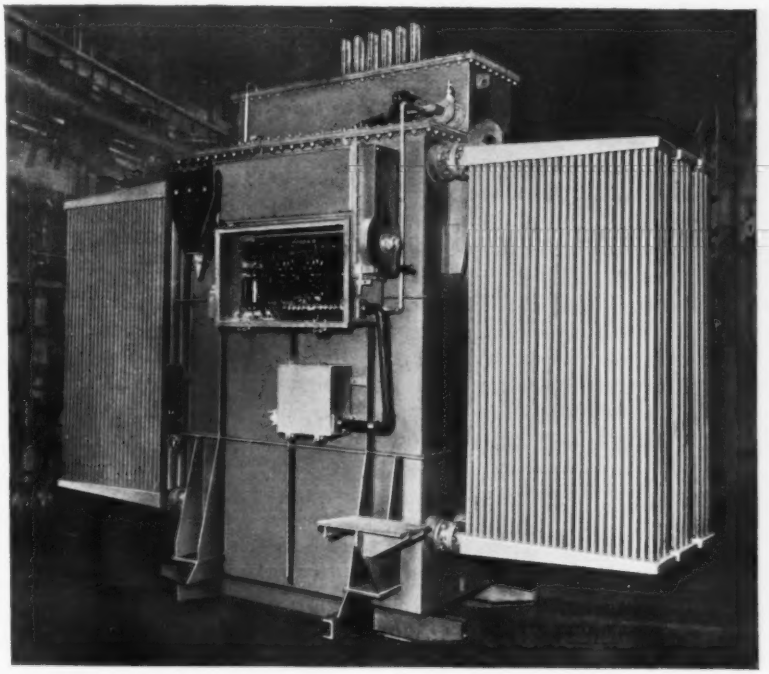


Fig. 6.—2,300 kVA. Naturally-cooled (ON) Arc Furnace Transformer, showing Expansion Vessel and externally-mounted Off-circuit Tapchanger with cover of motor-operating mechanism removed.

The additional height of the transformer inherent in this arrangement is found in most furnace plant layouts to be advantageous rather than otherwise, and a little careful consideration of the limitations occurring in each particular case, will overcome any possible objection to the construction on the grounds of transport difficulties.

The practice of Furnace Engineers differs considerably in respect of the cooling of arc furnace transformers, and all the usual forms of transformer cooling have been supplied for one plant or another. Since a certain amount of water must be provided for cooling purposes about the furnace, e.g., for the electrode clamps, it is a simple matter in most installations to arrange for water-cooling of the transformer, the quantity required being very small even for large transformers. As a water-cooled transformer is of compact construction, this scheme is particularly suited for situations where it is desired to keep the plant within very limited dimensions, such as when installing a furnace in whatever space happens to be available in an existing works.

Forced circulation of the oil through a separate water cooler by means of a motor-driven pump (OFW cooling) is more generally adopted than cooling by water-piping immersed in the oil in the transformer tank (OW cooling), as the elimination from the latter of external apparatus is offset by the smaller proportions of the transformer itself when designed for forced oil-circulation. By mounting the cooler and

pump on an extension of the underbase of the transformer, a very compact arrangement may be obtained, and the complete lining up and sealing of the oil circulating system in the Works before despatch avoids any possibility of trouble due to faulty erection or uneven foundations for the transformer and separate cooler.

The question of maintenance once more comes to the fore in affirming this choice, as the failure of an immersed cooling coil due, say, to corrosion, would involve a very much more elaborate repair than the replacement of a cooler unit. On the other hand, the separate cooler may be constructed so that quick cleaning of the oil and water passages can be carried out as a regular part of the long-term maintenance programme, an impossibility with an immersed coil.

There are, however, objections to the general principle of cooling transformers by water, a large body of electrical engineers not only concerned with furnace plant holding that to encourage the close proximity of water to transformers is taking a deliberate and unnecessary risk. The variable quality of cooling water obtainable and its effect upon the cooling system introduces an uncertainty to the selection of suitable materials and so forth, and the cases that have occurred of trouble with water-cooled transformers are a sufficient deterrent to many Engineers from considering the installation of such equipment.

In selecting the form of air-cooling most suited to arc furnace transformers, the general layout of the furnace plant must be taken into consideration. It is essential for the transformer to be in reasonably close proximity to the furnace in order to keep within bounds the length of run of heavy-current secondary busbar, and the furnace may be one of several installed centrally in a large melting-shop. Thus the transformer must also be installed in the centre of the building and as it is generally accepted that the air in the shop itself is unsuited (without treatment) to come in contact with the transformer, an arrangement of ventilating ducting must be provided to bring the cooling air in from outside the building or through a filter system from the shop.

For smaller transformers there is no doubt that natural cooling provides the cheapest form of construction of the transformer itself, but a little further consideration of the arrangements that must be made for the supply of cooling air may perhaps influence the final choice in favour of a slightly more expensive transformer with the object of reducing the outlay upon the plant as a whole. With transformers of the larger capacities it is undoubtedly desirable in the interests of economy to keep the quantity of cooling air to the necessary minimum, and therefore to employ

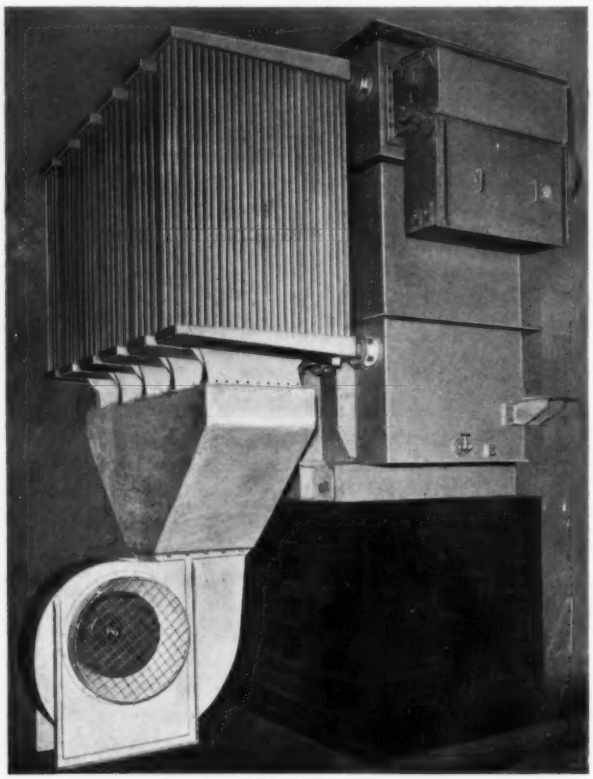


Fig. 7.—3,500 kVA. Air-Blast-cooled (OB) Arc Furnace Transformer, showing Diffuser Ducts and Fan suitable for mounting in a pit.

it in the most efficient manner, that is : it should be directed from the duct over the cooling surface of the transformer. The fan required for drawing the air through the duct should be installed adjacent to the transformer, as at this point the quantities may be closely determined for the purpose of assigning a suitable rating, though where the length of run of duct is considerable or several equipments are drawing air from a common main duct, supplementary fan equipment will probably be needed.

The transformer cooling surface may be provided in two ways ; either by radiators built on to the walls of the tank, through which the oil circulates by natural thermo-syphon effect (OB cooling), or by a separate cooler through which the oil is forced to circulate by means of a motor-driven pump (OFB cooling). The former is akin to a naturally-cooled (ON) unit, although the forced draught of cooling air directed over the surface of the tubes by correctly designed diffuser ducts enables a saving to be made in the number of radiators required, which is frequently sufficient to cover the cost of the fan equipment. The latter system on the other hand, due to the forced circulation of the oil, permits of an increase in the electrical rating of the materials and produces in the larger sizes transformers of considerably lower initial cost. The overload capacity of the former is, however, better than that of an OFB cooled transformer, so there is much to be said for both types on a number of counts.

An advantage shared by water-cooled and OFB-cooled transformers is that the transformer chamber may be made almost airtight or with the very minimum of ventilation, since the proportion of the transformer losses dissipated from the plain surface of the tank itself is insignificant and not taken into account when calculating the dimensions required for the cooler. The separate air-blast cooler equipment may actually be mounted outside the transformer chamber, though it is better to give it mechanical protection by enclosing it with the transformer and providing sealed ductwork from the cooler inlet and outlet to the outside air. With this arrangement it is not essential to draw the cooling air from outside the furnace shop provided the air entering the cooler can be kept reasonably temperate, as it is then only necessary to clean the radiating surface occasionally by brushing or with a compressed-air jet.

Where these forms of cooling are deemed unsuitable or unacceptable, the problem of feeding conditioned air to the transformer chamber must be given serious consideration. It may be of interest to ponder upon whether too much attention has not hitherto been paid to the obtaining of cooling air from the outside of the buildings in which Arc Furnaces are installed. The atmosphere of a district devoted to heavy industries particularly can hardly be described as clean, and inspection of installations so arranged, having the transformer housed in an enclosed chamber fed through air ducting, discloses that there is often carried into the chamber along with the so-called " clean " cooling-air no small quantity of dirt which the comparatively still conditions obtaining in the chamber encourage to deposit itself upon all the horizontal surfaces of the transformer. In spite of this the transformer will not be affected provided care is taken to ensure that dirt—especially if it contains metallic particles—is not permitted to accumulate around the bare terminals, with consequent risk of flashover and short-circuit.

Filter equipment may, of course, be introduced, and its use is indeed to be commended under conditions where it will be convenient as well as effective, but where the air is heavily polluted the outlay and maintenance costs tend to discourage even the most scrupulous among furnace users. If not given regular attention, or if allowed to become choked with dirt, a filter may actually become a source of trouble by throttling the supply of air and causing the transformer to overheat. There may, therefore, be a case for mounting the transformer (naturally cooled) exposed to the atmosphere of the furnace shop and encouraging the free circulation of air around it not only for cooling purposes but to prevent conditions arising favourable to the settling of the particles of dirt. A certain amount of mesh screening would be required to give mechanical protection and compliance with the regulations

governing such installations, and it would evidently also be necessary to protect the terminals and the L.V. busbars from anything falling or hanging from above, say from a crane. It has already been mentioned that the tap-changer motor-operating mechanism should be dust-proof, and all other parts of the transformer are totally enclosed and immersed in oil. It would therefore appear that the occasional application of a compressed air jet to the clearing of any deposited dirt from around the bare terminals should be sufficient to keep equipment laid out in this manner, in satisfactory condition.

It may be too early to prophesy the adoption of this form of layout as an approved standard, but it will be interesting to see whether the trend of development proves to be following along these lines. The Company are always anxious to keep abreast of the changing opinion of the users of their plant and to collaborate in the development of improved equipment on the basis of practical experience gained. As builders of over a score of the larger sizes and an aggregate of over 100,000 kVA. of transformers for steel melting arc furnaces, most of which have been delivered within the last few years, the Company may fairly claim to be closely in touch with the most modern practice and to have unrivalled experience in this class of work.

Tudor Black

WATERPROOF DRAWING INK

Sheer merit has won this ink the esteem it enjoys to-day. It possesses exceptionally free-flowing qualities — yields solid, light-resisting lines — will not jellify or clog the pen — does not readily evaporate in the palette.

E. N. MASON & SONS LTD., *LONDON BRANCH:*

THE FIELD HOUSE, BREAMS BUILDINGS, CHANCERY LANE, E.C.4

Telephone: CHANCERY 6411 (5 lines)

STRAKER BROTHERS LIMITED

PRINTERS and STATIONERS

THE BISHOPSGATE PRESS :: ESTABLISHED 1800

194-200, BISHOPSGATE, LONDON, E.C.2

TELEPHONE: BISHOPSGATE 2444 (4 LINES)

INCORPORATING: ADLARD & SON, LTD., DORKING, SURREY
ESTABLISHED 1766

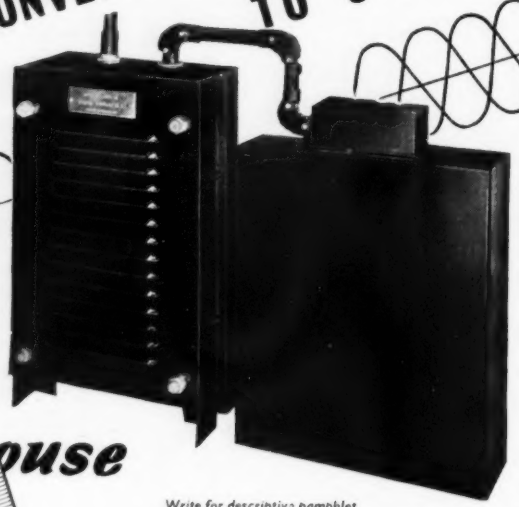
PRINTERS TO SCIENTIFIC AND LEARNED SOCIETIES

We invite your enquiries for all classes of Printing and Stationery

GENERAL PRINTING. ILLUSTRATED PRICE LISTS. WEEKLY AND MONTHLY JOURNALS. SCIENTIFIC PUBLICATIONS. CATALOGUES. POSTERS. SHOWCARDS. STATIONERY BY ALL PROCESSES. LOOSE LEAF FORMS AND SHEETS

All classes of BINDING

STATIC CONVERSION OF SINGLE-PHASE TO 3-PHASE



Westinghouse

STATIC PHASE CONVERTER

Write for descriptive pamphlet No. 11M to Dept. E.E.J.

Westinghouse Brake & Signal Co. Ld.

Pew Hill House, Chippenham, Wilts.

Represented in India by Saxby & Farmer (India) Ltd., Calcutta.

Represented in AUSTRALIA by McKenzie & Holland (Australia) Pty. Ltd., Melbourne.

The patented Westinghouse *static* phase converter comprises simply two reactances and a condenser, and will not only change the number of phases, but also the voltage. The input power factor is as good as, and in fact somewhat leads on, the power factor of the load ; the output voltage wave-form is good. Under normal conditions, the efficiency is of the order of 95%. Further, the output phase balance is constant over a wide range of loading, and the phases may easily be adjusted to a state of equality for abnormal loads or changes in mains voltage.

'ENGLISH ELECTRIC'

HIGH RUPTURING CAPACITY
NON-DETERIORATING

CARTRIDGE FUSE LINKS

Install "English Electric"

and be Safe

"English Electric" Cartridge Fuse Links, Indicating Type, are available up to 800 amps. and comply with BS. No. 88/1939, Categories 440.A.C.4 and D.C.4.

A complete range of Metal-clad and open-type apparatus incorporating "English Electric" fuses is also available.

Publications sent on request.

THE ENGLISH ELECTRIC COMPANY LTD.
—STAFFORD—

SOLID & STRANDED CONDUCTORS IN H.C. COPPER AND CADMIUM COPPER, COMMUTATOR BARS, END RINGS, ROTOR BARS, STRIP, RAIL BONDS, FORGINGS, BATTERY LINKS, TROLLEY WIRE, BUS-BARS

COPPER PRODUCTS FOR THE ELECTRICAL INDUSTRY

Head Office:
MARTINS BANK BUILDING, LIVERPOOL, 2

London Office:
168 REGENT STREET, W.1

ESTABLISHED 1783

Thomas BOLTON & Sons Ltd

Greater mobility, speed, comfort, silence and safety point to 'A.E.C.–English Electric' trolley buses as the logical means of modernising existing electric systems for public transport work.

TROLLEY BUS OPERATORS INCLUDE—

HOME: Belfast, Birmingham, Bradford, Darlington, Hastings, Huddersfield, London, Newcastle, Nottingham, Notts & Derby Traction Co., Portsmouth, Reading, Rotherham, Southend, Walsall.

OVERSEAS: Adelaide (South Australia), Durban (South Africa), Milan (Italy), Johannesburg (South Africa), Montreal, Edmonton (Canada), Sydney (New South Wales), Moscow (U.S.S.R.), Odense (Denmark).

THE ENGLISH ELECTRIC CO. LTD. STAFFORD
THE ASSOCIATED EQUIPMENT CO. LTD. SOUTHALL, MIDDX.

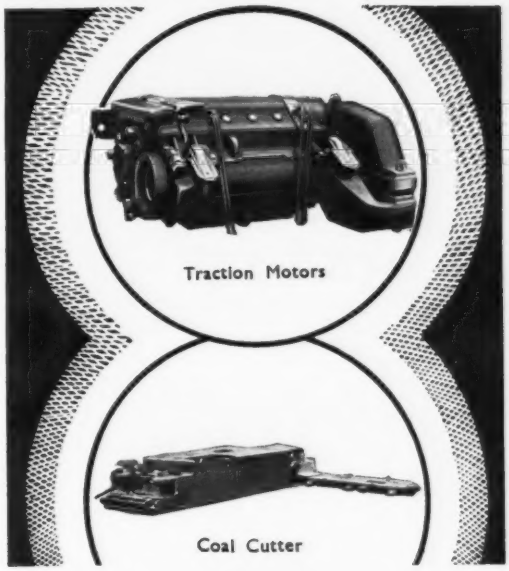
INDEX TO ADVERTISERS

Associated British Machine Tool Makers, Ltd.	XII
Associated Equipment Co., Ltd.	X
Attwater & Sons	VII
Babcock & Wilcox, Ltd.	I
Bolton, Thomas & Sons Ltd.	IX
Broadbent, Thos. & Sons, Ltd.	III
English Electric Company Limited	IX, X
Ioco Rubber & Waterproofing Co., Ltd.	II
London Electric Wire Co. & Smiths Ltd.	XI
Mason, E. N., & Sons, Ltd.....	VII
Micanite & Insulators Co., Ltd.	IV
Siemens Brothers & Co., Ltd.	VI
Sterling Varnish Co., Ltd.	V
Straker Brothers Ltd.	VIII
Taylor, Tunnicliff & Co., Ltd.	II
Walker, James & Co., Ltd.	V
Westinghouse Brake & Signal Co., Ltd.	VIII

All communications respecting Editorial Contents and Advertising Rates should be addressed to The Editor, The English Electric Journal, The English Electric Company Limited, Stafford.

When communicating with Advertisers please mention English Electric Journal.

TYPICAL APPLICATIONS



Lewbestos
REGD.

(Pure Asbestos Fibre)

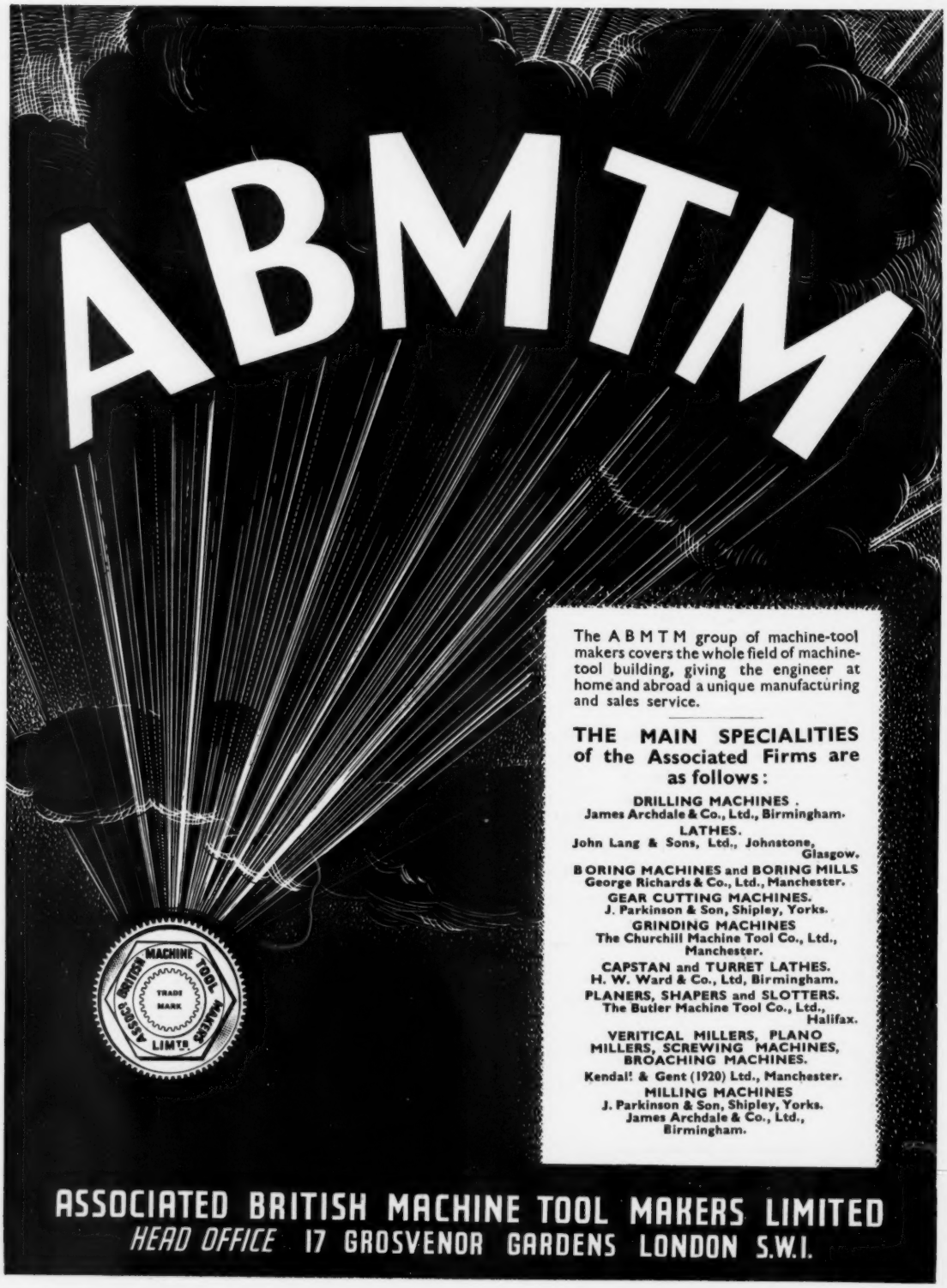
INSULATED WIRES

•

COILS WOUND WITH
"LEWBESTOS"
CONDUCTORS
DO NOT BURN OUT
WHEN SUBJECTED TO
HIGH TEMPERATURES

Our booklet on Modern Armature Winding gives practical and technical information. SEND FOR IT NOW!

THE LONDON ELECTRIC WIRE COMPANY and SMITHS, LIMITED
Church Road Leyton, London. E.10.
Tel: LEYTONSTONE 3636 (10 lines) Telg: "LEWCOS, LONDON"



The A B M T M group of machine-tool makers covers the whole field of machine-tool building, giving the engineer at home and abroad a unique manufacturing and sales service.

THE MAIN SPECIALITIES of the Associated Firms are as follows:

DRILLING MACHINES
James Archdale & Co., Ltd., Birmingham.

LATHES.
John Lang & Sons, Ltd., Johnstone, Glasgow.

BORING MACHINES and BORING MILLS
George Richards & Co., Ltd., Manchester.

GEAR CUTTING MACHINES.
J. Parkinson & Son, Shipley, Yorks.

GRINDING MACHINES
The Churchill Machine Tool Co., Ltd., Manchester.

CAPSTAN and TURRET LATHES.
H. W. Ward & Co., Ltd, Birmingham.

PLANERS, SHAPERS and SLOTTERS.
The Butler Machine Tool Co., Ltd., Halifax.

VERITICAL MILLERS, PLANO MILLERS, SCREWING MACHINES, BROACHING MACHINES.
Kendal! & Gent (1920) Ltd., Manchester.

MILLING MACHINES
J. Parkinson & Son, Shipley, Yorks.
James Archdale & Co., Ltd., Birmingham.

ASSOCIATED BRITISH MACHINE TOOL MAKERS LIMITED
HEAD OFFICE 17 GROSVENOR GARDENS LONDON S.W.I.